HOW WIRELESS CAME

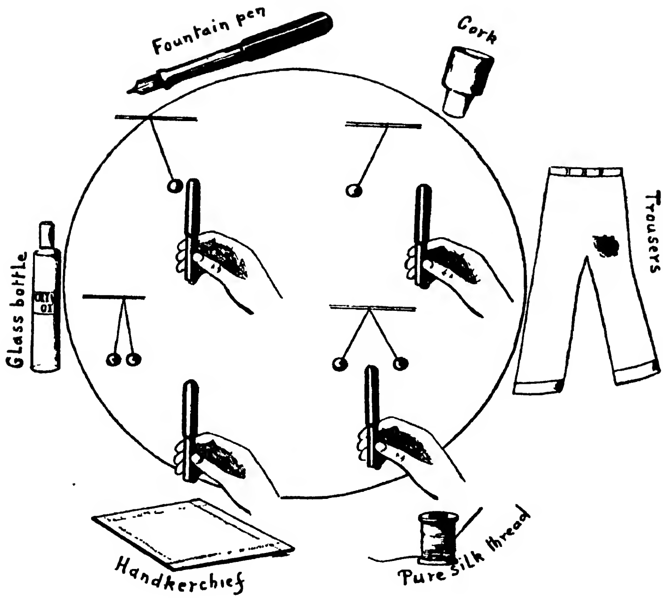

FIG. 15.—A complete collection of apparatus to begin the study of electricity (see p. 90).

BY

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HOW WIRELESS CAME

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ILLUSTRATIONS

side of the world; I have heard the magic that a musician knew how to coax out of a piece of stretched cat-gut; I have laughed at some very silly jokes and quickly turned the knob to drown out other sounds which pleased me less. I confess to you that nothing pleases me more than when somebody announces: "You are now going to listen to . . ." and I show him that I know better by drowning him in a deep pool of silence. Now the wooden box is quiet.

I sit by the fire and wonder what my friend Borrea Bungalee Boo would think of that box. Do you know Bungalee Boo?

> King Borrea Bungalee Boo
> Was an African man-eating swell,
> His sigh was a hullabaloo
> And his whisper a horrible yell,
> A most horrible, horrible yell.

Suppose I could bring him from his savage village deep in an African forest into this room to-night. I stand him by the fire and twist the knobs of the wooden box; a crooner springs to life; Boo bristles; he scents an enemy hidden in the box; an assegai hurtles; the radio set is smashed; the crooner ceases from crooning; and Boo seeks amid the ruins for a dead body.

Or perhaps it was not a crooner; perhaps a beautiful sound of music was coaxed out of the

silent ether. Boo listens ; he falls to the ground to worship the little brown god.

I envy King Borrea Bungalee Boo hearing his first wireless set, for to him the box is magic ; to be worshipped or feared ; while to us—what is it ? Too often just a box, a wireless set bought at a shop, turned on or off, repaired when necessary by a man who is paid to do it ; and, in the end, thrown out for a better set.

And yet if we knew the story of how that box came ; of how mankind thought and fought, adventured and worked for hundreds of years to find it ; then I think it would become as wonderful to us as it would be to Boo. And it is that story that I shall try to tell.

II. OF TWO MYSTERIOUS MAGICAL STONES AND HOW THEY PROVED TO BE THE CLUE TO A LONG SEARCH

It is a long story, and it begins in the days of the ancient Greeks of whom we read in Homer's stories of war and wandering. These heroes lived in a world of wonder ; to them there was nothing that had not got its own particular magic. There was magic of trees and of stars, of shells and of precious stones ; and they were for ever on the look out for new things that would have new magical powers.

Now and then as they sat on the seashore,

mending boats or fishing nets, they would see washed up by the waves a brownish-yellow stone; a strange stone because it was so light that it floated upon the waves. Moreover, in its half-transparent depths they could see sometimes ants and flies as it were buried in solid light.

Could there be the least doubt that such a stone was magical? Clearly it was a stone to be kept and cherished for the sake of the good it might do to the wearer in war or love or both. So these men would always pick up these stones when they found them, and rub them against their woollen sleeves to polish and dry them. And it was then that the stone gave proof of its magic, as they had expected, for when they rubbed it, behold, little bits of thread and fluff and straw leaped through the air and hung to it, a thing never seen before. Certainly, they argued, a stone that could call things from a distance to its side would be valuable to its fortunate wearer. And so it came about that when the learned men wrote long books about the magical power of jewels and precious things, they gave a specially honourable place to Elektron, as they named this floating yellow marvel.

And it has turned out that they were perfectly right. More magic than they could ever dream of was hidden in that strange power of attraction. When the first man rubbed a piece of Elektron,

or amber as we call it, against his woollen garment and noticed that pieces of fluff jumped towards it, he was making the first experiment in the long search that led to the coming of all sorts of modern wonders, including wireless itself.

More than two thousand years later, an Englishman, Gilbert by name, discovered that many other things besides amber had the power of attracting light objects, when rubbed; and he called all such things "electrics", meaning by that word, "things which attract for the same reason that Elektron or amber does".

From his day the science that deals with these "electrics" has been called the science of Electricity and the magical power hidden in the amber is known to all of us by this word that comes from the Greek name for amber, Elektron—Electricity. And in 1891, when men had discovered the smallest piece of electricity that it is possible to have, they called it an electron in honour of those men who so long ago had rubbed Elektron against their sleeves and noticed the strange way in which it attracted things to itself.

There was another stone that excited the ancients with its magical behaviour, and it was found especially in a part of Asia Minor called Magnesia. Just as Elektron attracted light objects, so the Magnet, as they soon learned to call this black, heavy piece of rock, attracted iron to

it. And this particular piece of magic they naturally called Magnetism.

In course of time it was discovered that the power of Elektron and the power of the Magnet were very closely related, that you could not study the one without coming across the other, so that the science of Electro-magnetism was born.

Two mysterious magical stones, almost worshipped by our ancestors, that is one end of the story, and our wireless set at the other.

III. OF THE DANCING ATOMS AND MOLECULES OUT OF WHICH ALL THINGS ARE MADE

It was a long time before men were ready to discover the electron, or smallest piece of electricity. First of all they had to discover the smallest piece of matter itself. "Of what is the whole world made?" they asked themselves; and their search for an answer led them to some astonishing surprises.

For example, unless you are a very good sailor you must have felt glad at some time or other to get off a rough choppy sea and to feel the solid ground beneath your feet. Does it surprise you to hear that this solid ground beneath your feet is mostly empty space, and that the parts of which it is made are all rushing about so fast that compared with them the roughest sea is as still as a sea of ice?

Does it surprise you to hear that the chair upon which you are sitting is made up of countless billions of tiniest pieces, each one rushing about at speeds which make the fastest aeroplane seem like a tortoise? If any one of these tiniest pieces could rush on without being interrupted, it would get round the world in a very few seconds, but no piece of your chair will ever get to China because every piece bumps into another piece about eight billion times a second, so that they never get anywhere.

And does it surprise you that your own body is nearly all emptiness dotted with inconceivably small amounts of something which it is safest to call simply bits of "Not-emptiness"?

All these things men had to find out about matter, about the stuff of which the whole universe, including our own bodies, is made, before they could find the electron out of which electricity is made. It is a strange story, but this is not the place to tell more of it than is absolutely necessary for understanding our own story, which is the coming of wireless. If you would like to know more you can find it in another of my books [1]; and here are the bare bones of it. . . .

When men began first to wonder about how the world was made, they asked themselves what would happen if they went on cutting a piece of

[1] *Inside the Atom* (Routledge, 5*s*.).

matter into smaller and still smaller pieces. In course of time they found that everything in the world, rocks, trees, your body, a chair, the sun, air, water, was built out of ninety-two different kinds of smallest pieces, or atoms, as they called them, because atom in Greek means " that which cannot be cut ".

Out of these ninety-two sorts of atoms everything in the world is made. When a thing, like gold or iron, is made of only one kind of atom, it is called an element ; so that there are ninety-two elements ; but most things are built out of more than one kind of atom, as for example water. The smallest piece of water is made out of two atoms of hydrogen and one of oxygen, clinging together in a way we shall soon discuss. When there is more than one kind of atom in the smallest piece of a thing we call that smallest piece a molecule, to distinguish it from the smallest piece of an element.

You can cut the smallest piece of water, a molecule of water, smaller, and then although it ceases to be water it is still an atom of matter, either hydrogen or oxygen as it may happen.

Some molecules are made up of far more than two or three atoms. Thus the molecules of protoplasm out of which our bodies are made contain hundreds of atoms in complicated patterns, and when these patterns break down the proto-

plasm dies. But it is interesting to note that although protoplasm is so complicated there are only a very few different elements found in our bodies. Indeed out of the ninety-two kinds of atom in the world only about fifteen are used to make protoplasm.

Out of every hundred atoms in our body, sixty-five are oxygen atoms, eighteen are carbon, ten are hydrogen, three are nitrogen, two are calcium and one phosphorus, while the hundredth may be any one of nine other kinds of elements.

Of course all these atoms are far too small to be seen even in the most powerful microscopes, but we know that they really exist because all sorts of things that we can see are best explained by supposing that they do exist. And it is very important at the start of our story that you should get into the habit of thinking of everything in the world being made up of these tiny atoms.

IV. HOW HEAT IS NOTHING BUT THE MOVEMENT OF MOLECULES ; WHY THE THERMOMETER GOES UP ; WHY HOT WATER BREAKS A GLASS ; WHY A MOTOR-CAR TYRE BURSTS

One of the strangest things that men have discovered about these atoms and molecules, these smallest parts, is that they are never still for a single instant.

Look at the chair upon which you are sitting: every one of its molecules is restlessly racing around at a very rapid pace. None of them, as I have said, ever get very far, because they are always banging into one another billions of times a second.

Sometimes the molecules are dancing faster than at other times, and we can tell this in two different ways. First of all our bodies feel the motion of molecules and we call it heat. When we say, " It is a hot day ", we mean the molecules of air about us are moving more rapidly than usual, or than we ourselves happen to like. What happens is that the sun speeds up the air molecules to a more violent dance and then the molecules of the nerve ends in our skin are hit and bounced into more often than they like and register the fact in our brain in the way that we call " being hot ".

The other way that we know that the molecules of some substance are dancing faster is that when this happens every molecule gets farther away than usual from its neighbours, so that the substance expands. The column of mercury in a thermometer, for example, goes up in hot weather because all the mercury molecules are separating themselves more than usual from their neighbours.

Anything whose molecules are dancing faster

than the molecules of other things around it will sooner or later speed up those other molecules and be a little slowed down in the process, until all the molecules in the neighbourhood are dancing at the same pace. That is why a cup of tea cools to the temperature of the room, and a block of ice melts. Indeed, all the molecules in the universe will go on banging into one another and speeding one another up or slowing one another down until all of them are moving at the same pace, and then the whole universe will be one temperature.

When you sat down on your chair, you probably felt it cool against your body: that was because your body's molecules were dancing faster than the chair's. Now that you have been sitting for some time the chair has become warmer: your body's molecules have hurried the chair's molecules until they are all moving at the same speed.

If you think of things in terms of atoms and molecules, and heat as motion of these molecules, you will easily see why:

1. The thermometer goes up on a hot day and down on a cold one. The slower the molecules dance the closer they huddle together.

2. You may break a glass by pouring hot water into it. The water molecules dancing very fast try to push the glass molecules into a violent

that is "not-emptiness" is rather like a needle in a haystack without any hay.

Suppose we carve up a drop of water. First we get down to the smallest piece or molecule of water. Next we find that we can break this up into three atoms, two of which are hydrogen atoms. We will take one of these hydrogen atoms and enlarge it to the size of St. Paul's Cathedral. If you were to imagine St. Paul's with a flea in the middle and a fly flying round the walls, only *no walls*, you would have quite a good picture of a hydrogen atom.

Enlarge the hydrogen atom still farther; you would find in the centre a speck as big as the earth and, flying round it at the distance the earth is from the sun, a larger speck, perhaps the size of the sun. All the rest would be empty space.

In short, far from the atom being like an infinitely small grain of hard sand, it is much more like a solar system with planets revolving at huge speeds round a central sun, and all of it contained in a space almost too small to imagine.

And so the solid chair in which you sit with such confidence is made up of molecules dancing so fast that they hit into one another eight billion times a second; and these molecules are made up of atoms, which consist of infinitely tiny specks revolving in vast depths of emptiness. What do you think of solid matter now?

If we could pump out all the emptiness from the atoms of the earth, leaving behind nothing but the flies and the fleas, as we called them just now, all that would be left of this vast ball on which we live, would be about the size of an orange.

There is of course no force in the universe that could do this, but it is interesting to note in passing that there are stars in which quite a large amount of the emptiness has been pumped out of the atoms. For example, if you look out in the evening sky in winter you will see, low down to the left of Orion and his Belt, the flashing light of Sirius, the Dogstar. Sirius is famous enough because it is many times brighter than any other star. Now revolving around Sirius, hidden from the biggest telescope by distance and faintness, is a small companion star, and astronomers have shown that so much of the emptiness has been pumped out of its atoms that a cubic inch of its matter weighs a ton. How do they know? Ah! that is yet another story.[1]

VI. OF THE INFINITELY SMALL SPECKS HANGING IN UTTER EMPTINESS, WHICH IS ALL WE ARE

We must now find out what these specks lost in emptiness, this fly and flea, can possibly be. They are not matter, because the atom which

[1] *Inside the Atom*, p. 116.

contains them is the smallest part of the kind of matter called hydrogen. But assuredly they are the stuff of which all matter is made.

The atom of hydrogen consists of emptiness with one speck in the middle and one speck revolving round it on the edge. Although this speck is bigger than the central one, it is so much lighter than it that in weighing the atom as a whole it can be left out of the reckoning.

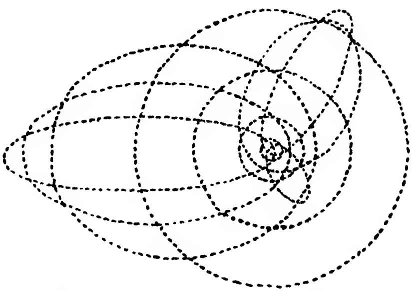


FIG. 1.—A hydrogen atom with all the paths the single electron can follow.

For the moment I am going to call the central speck P-speck and the revolving speck E-speck.

The E-speck can revolve round the P-speck in several different paths, and here is a picture of these paths. Pause for a moment to think how remarkable it is that though no one has or can ever see a hydrogen atom, we can know for certain that the E-speck can move in these paths and in no others.

Sometimes the E-speck jumps from one path

to another, and it seems to be able to do this instantaneously and without going through the space between ; but this is a mystery into which we cannot go here. Remember only that when certain things happen to the atom, the E-speck jumps from one of its paths to another.

Sometimes also the E-speck can jump or is knocked right out of the atom and sometimes another wandering E-speck joins up with the original E-speck, so that for a time there are two E-specks where usually there is but one. Now when this happens we learn a most important fact about both these specks, a fact which, as we are going to see, explains the magic in that ancient yellow stone that puzzled Greek heroes long ago.

This is the fact : every P-speck in the universe attracts every E-speck in the universe, and no P-speck is content unless it has its own faithful E-speck to revolve around it. In the same way no E-speck is content to be without a P-speck to revolve around. And also every P-speck repels every other P-speck and every E-speck repels every other E-speck.

And so if a hydrogen atom is knocked into by another atom so violently that its revolving E-speck is torn away, the P-speck left alone is never content until another E-speck comes along to keep it company. Nor is the hydrogen atom content to have an extra E-speck thrust upon it

from outside. It will shed the intruder at the very first opportunity. We shall soon know how important this one fact is in our story.

The next surprising thing about these specks is that the only difference between one kind of atom and another is the number of E-specks and P-specks each one contains. The only difference between the oxygen we breathe, for example, and a piece of iron, is that their atoms have a different number of these two kinds of specks hurtling through their emptiness.

Think carefully of this : not only is everything in the world, however complicated it may seem, a bird flying, a fish swimming, mud or blood, sea or sky, sun or insect, made up of only ninety-two kinds of building bricks or atoms, but these ninety-two different kinds of atom are all made up of nothing more than a varying number of P-specks and E-specks.

So far we have only looked at a hydrogen atom, and we began with this because it is the simplest atom of all. Fig. 2 is a sketch of the second atom on the list ; that is to say, the atom that is next lightest to the lightest atom, hydrogen.

This helium atom is four times as heavy as a hydrogen atom, and as we know that in weighing atoms we can leave the E-specks out, that means that it must have four P-specks in its centre or nucleus. It also has two E-specks revolving

round this nucleus, and as we know that in every atom there must be an equal number of the two kinds of speck to keep things tranquil, we suppose that there are two more E-specks in the nucleus, cementing the P-specks together, as it were.

The only difference between an atom of hydrogen and an atom of helium is that the first has one of each kind of speck and the other four of

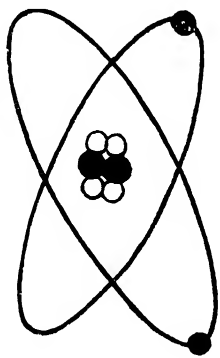


FIG. 2.—Helium, the second lightest atom. Two specks revolving round six other specks.

each kind, and yet that is enough to make everything that they do quite different. For example, hydrogen is very inflammable, but helium cannot be made to burn in any way. That is why, although hydrogen is the lighter, helium is the better gas for filling balloons.

Again, hydrogen joins up with oxygen to make water, and with other kinds of atoms to make

the list, we find that it is Krypton, which means Hidden, and it was so called because it is so inert, so lazy, so much an atom that walks by itself, that it was very hard to find it at all. In short, the atoms with all their rings complete are the

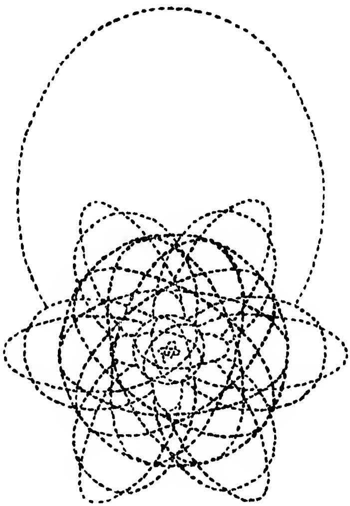


FIG. 3.—Copper Atom. The dotted lines are the orbits of the revolving electrons. Notice that one leads far away from the nucleus.

only thoroughly contented ones, and therefore the only thoroughly lazy ones.

So it seems that an atom requires two things to be thoroughly content:

1. To have, as we saw, a perfect balance between its P-specks and its E-specks.

2. To have all its rings perfectly full. If it has one ring, it wants two revolving E-specks; if it has two rings, it wants ten; if three, eighteen, and so on.

Now you can see that there are only a few atoms that can have both these things at the same time. They are the atoms that have the right number of P-specks and E-specks in their nucleus to balance two, ten, eighteen, thirty-six, fifty-four and eighty-six revolving E-specks; and sure enough all these atoms exist and all are inert, lazy gases. They have been called Helium (because its existence was first discovered in Helios, the Sun); Neon, the New; Argon, the Work-shy; Krypton, the Hidden; Xenon, the Stranger; and Radon, the inert gas that comes when Radium breaks up into new elements. Being perfectly content, these do nothing at all and never join up with other elements.

Contented things, like a certain sort of self-satisfied people, are never interesting and we only nod at them and pass on to ask what the less contented atoms do. The answer is, they try to eat their cake and have it.

They try to have a perfect balance between E-specks and P-specks and at the same time to have a full house of revolving E-specks in all their rings. The way they try to do this is by stealing or forcibly borrowing or sharing one

another's E-specks. They cannot simply annex wandering E-specks, because that would upset the balance between their P-specks and their E-specks and the extra E-specks would fly off at the very first opportunity; their plan is craftier than this.

Look at this oxygen atom, for example. It is floating around as part of the air in our room along with a number of nitrogen atoms. It is having quite a merry dance with millions of collisions a second. And it is fairly content because it has sixteen P-specks and eight E-specks in its nucleus, and, to balance them nicely, eight more E-specks revolving, two in an inner circle and six in an outer circle.

It is not quite content. It would so much rather have eight electrons in that outer circle. But it cannot just kidnap a couple of passing E-specks because there would not be enough P-specks to hold them; they would get away almost immediately.

Presently our oxygen atom finds itself near two hydrogen atoms. They too are fairly content, because they each have one nicely balanced P-speck and E-speck; but they would much rather have two E-specks in their one and only ring.

Bang! What has happened? The oxygen atom and the two hydrogen atoms have disap-

peared and in their place is a molecule of water. The oxygen atom has filled up the two vacant places in its outer ring by borrowing the E-specks from the two hydrogen atoms ; but by so doing it has become hopelessly stuck to them, for their lonely P-specks, deprived of their E-specks, hang on grimly and refuse to be shaken off. The oxygen atom having now got two unbalanced E-specks can do nothing about it and has to accept the partnership as the price for completing a full house in its outer ring ; and the result is a molecule of water, a compound made of three unbalanced atoms clinging together.

That is why elements join together to make compounds ; it is an attempt to have two different kinds of comfort at once. And the really important thing for us to remember is that directly atoms become unbalanced in this way, if they do not compromise by forming compounds with other atoms, new forces of attraction and repulsion are brought into play. A lazy atom with both kinds of comfort is dead to the world ; a balanced atom with incomplete rings will content itself with joining up with other atoms in compounds ; but an unbalanced atom with too many or too few E-specks will never be at rest until it has so altered the outside world that it has made good its lack.

This restlessness of unbalanced atoms has been

taken by man and used to do the world's work. As we are going to see quite soon now, the reason that you and I can listen to a little brown box out of which come the voices and the music of a whole world is that we have learned to harness the restlessness of unbalanced atoms.

VIII. WHAT ELECTRICITY IS AND WHAT AN ELECTRON IS; AND HOW WE CAN BRUSH ELECTRONS OUT OF ATOMS

Keeping all that has been said about atoms and molecules, P-specks and E-specks well in mind, let us go back to the ancient heroes and their magic stones. Probably some female member of your family can supply you with a piece of amber from a necklace, but if not a piece of sealing-wax or a fountain-pen will do just as well, since both these are what Gilbert called an "electric".

Just as an ancient Greek may have done, rub your "electric" against a piece of wool or silk and watch how the little pieces of fluff fly. What you have really done is this: you have knocked a certain number of E-specks out of the atoms on the surface of the amber and attached them to the wool. That means that the amber atoms are unbalanced, they have too few E-specks to balance their P-specks. Bring any light thing close and the unbalanced amber atoms will pull

at it so as to try and steal enough E-specks from it to get balanced again, and so return to a state of comfort.

That is very simple, is it not? You have deprived some atoms of a certain number of E-specks and you are watching them making good their loss. Now, whenever you ring a front-door bell, or go by underground or tram, or light a lamp, or heat an electric stove, or listen to the radio, you are using this simple fact, that somehow, somewhere, atoms have been made poor in E-specks and you are helping them to get them back again in exchange for work done for you.

Or take a thunderstorm: great masses of air atoms racing along at different temperatures have brushed together in such a way that countless billions of atoms have had E-specks knocked out of them; the tension has got greater and greater; suddenly a huge rush of E-specks and unbalanced atoms takes place and we see a flash of lightning and know that the atoms have been able to balance themselves.

The ancients imagined that lightning was the flash of a god's anger, or of his weapon hurled at the earth. With our knowledge of atoms and their whirling specks we might draw a different picture of such a god of storms, and imagine him rubbing against the dark sleeve of the cloud in

which he clothes himself his lurid yellow electric stone. At least it is exciting to think that what we see in the angry sky is nothing more than what we can do with a piece of sealing-wax and our own trouser-leg!

And now it is high time to give the P-speck and E-speck their real names. The first is called a Proton, which means, in Greek, the first thing, because it is the foundation of the atom and therefore of all matter. The E-speck, as you have probably guessed, is called the Electron, because it is the smallest piece of the thing that is responsible for electricity.

I had a good reason for telling you about the doings of an electron before I told you its name. Names are dangerous things, because we often mistake them for explanations. Nobody knows what an electron *is*, we only know what it does. You know no more about electricity now that you have the word electron in your mind, than you did when you only talked of E-specks. To understand science is not a matter of knowing the names of things, but of knowing what things do. It is useless to know the names of the parts of a wireless set, if you do not know what the parts do.

Electricity, then, is the result of electrons and protons trying to get into a perfect balance within an atom of matter. It is important to us because

we have learned how to get a great deal of the world's work done in the process.

We will next learn whatever we can by examining one of the simplest ways in which mankind puts electrons to work.

CHAPTER II

HOW AN ELECTRIC BELL WORKS

I. WHAT AN ELECTRIC BELL LOOKS LIKE; AND THE STRANGE MOVEMENTS GOING ON WITHIN A COPPER WIRE; DANCING ATOMS AND WANDERING ELECTRONS

NEARLY every house has an electric bell, and I am going to take for granted that you can go to one and take off its cover and look inside. Fig. 4 is a sketch of what you will see. Notice the two things like cotton reels. If you can find an old bell which can be destroyed, you will find that these reels have a piece of iron inside them and very thin copper wire wound round them many times. The copper wire is covered with cotton, or perhaps silk. You will also see that at the end of these reels, not quite touching them, there is a piece of iron and that the bell-hammer is joined to it. The bell itself is usually below the cover. We will call all this the bell-unit.

Of course you know that there are other things

to the bell besides the bell unit. First, there is at the front door a bell-push for ringing the bell. Second, you will find in some cupboard a jar to which two wires are joined. Third, connecting the bell-unit, the bell-push and the jar there is

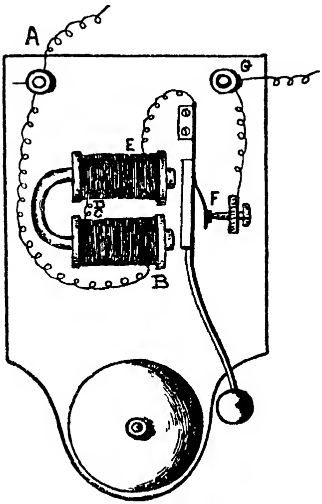


FIG. 4.—An electric bell. The wire runs through A-B-C-D-E-F-G.

copper wire. Fig. 5 shows us the whole *circuit*, as it is called.

Let us first take a careful look at the copper wire. After reading the last chapter, you will probably think of it rather differently from before. " Just a bit of wire ", it is indeed ; but what hidden complications are to be found in just a bit of wire !

As copper is an element, there is only one kind of atom in the wire, but it is dancing about and hitting its neighbours billions of times a second. When the room gets warmer the atoms dance more wildly and move farther off from one another, and yet it would be hard for you to separate any of the atoms altogether and break

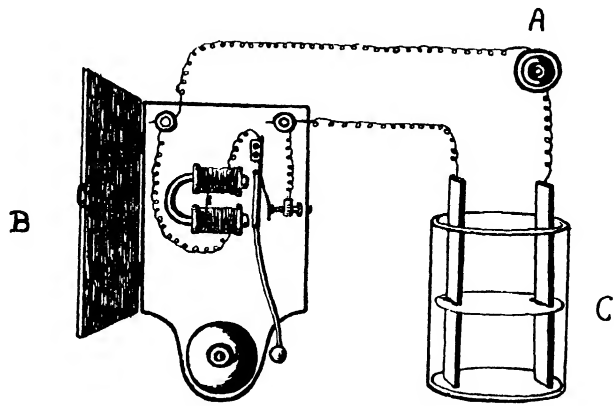


FIG. 5.—The complete circuit of an electric bell. A is at the front door, B in the kitchen, C hidden away in a cupboard.

the wire. Every atom attracts every other atom, even though they do not touch.

If you were to tie a piece of elastic to two tennis balls and hold one of them in your hand while you bounced the other, you would have a picture of how two neighbour atoms may be said to behave. The faster they move, the farther away from each other they get; but a force always

keeps them tied together, just as the elastic gets stretched, but always remains to hold the tennis balls together. When you break the wire you are pulling apart billions of minute tennis balls by destroying billions of minute elastic forces tying them.

Then consider the inside of each one of these copper atoms. In the centre is the nucleus which is made up of sixty-three protons tied together by thirty-four electrons. Round this complicated nucleus revolve twenty-nine more electrons in different paths. In Fig. 3 you saw drawn one path for each electron and for clearness' sake the draughtsman has left out part of nearly all the orbits. Remember that these orbits are only a very few of the many that may be taken by the twenty-nine electrons; one path has been shown for each. But all the time every electron is able to jump into several other orbits; so that altogether the sketch can only show a very little of the complicated things going on within every copper atom.

Notice, too, that there are rings of orbits like a series of petticoats round the nucleus, and finally notice that one of the electron orbits carries its electron far away from the centre.

This eccentric path is very interesting for us. Round and round it goes an electron, kept within the atom by the attracting force of the protons

in the nucleus. As it gets to the part of its path that is farther and farther away from the nucleus, that force gets less and less. Meanwhile all the neighbouring atoms are dancing back and forth, and it will happen from time to time that this electron will actually be as near the nucleus of another atom as it is to its own. Then comes a tug-of-war; the rightful owner of the atom hangs on, and the neighbouring protons pull; so that, especially if the neighbouring atom happens to be minus an electron just then, there is a good chance that our electron will change its quarters.

Or it may swing round and knock out one of the other electrons with a good direct hit; or it may be nearer the new nucleus than one of its own electrons, which therefore seizes the opportunity to get away in its turn to a third atom. In short, in any piece of copper wire you may be quite certain that at all times there are electrons passing from one atom to another haphazard in all directions. Also, of course, there will be large numbers of free electrons who are off with the old atom but not yet on with the new. Perhaps there will be as many of these free wandering electrons as there are atoms, all of them busily looking for disengaged protons, knocking into rapidly moving balanced atoms and bouncing away, or carefully avoiding one another as chance brings them together. All this excitement goes

on unceasingly second after second ; but we never know anything about it, because all the hurry being haphazard cancels out ; in spite of all the rush and tumble no electron ever gets from here to China, or for that matter very far from where it started from.

But supposing it were possible to control all this movement, to make it head in one direction ; what then ? Well, all movement means energy, and, just as haphazard movement going on in a copper wire means wasted energy, so controlled energy can be *put to work.*

Notice carefully that, thanks to the shape of some of the paths round which its electrons rush, the copper atom is specially suitable for passing electrons along from one atom to another. All metals have this quality more or less ; for example, zinc, out of which buckets and some old-fashioned baths are made, has even more free electrons than copper. Anything that gives an easy passage for electrons is called a good conductor. A bad conductor is called an insulator.

For the moment, then, our copper wire, in spite of the energy shown by its atoms and electrons, is not very useful because that energy is not being directed anywhere in particular.

You will notice another thing about the wire which makes up our bell circuit. It is covered with some sort of material, cotton probably or

rubber. This is because, unlike copper or zinc, the atoms in these substances do not let electrons move from atom to atom easily. They are bad conductors or insulators. We bind them round the wire because we are going to make electrons in the wire move in a special direction round the wire and we do not want them to go off in any other direction.

So the copper wire is a road along which electrons may move from one of the three other objects in this bell circuit to the others. How do we make the electrons move to suit our own plans?

II. HOW WE CAN HARNESS THE WANDERING ELECTRONS TO DO OUR WORK AND HOW WE LEARNED THIS FROM A FROG WHOSE LEGS JUMPED AFTER IT WAS DEAD. THE WAY IN WHICH A VOLTAIC CELL WORKS

We can make the electrons move as we desire if we take advantage of one rule that free electrons obey. Although their movements are so haphazard, free electrons in a conductor always arrange themselves as soon as they can equally all through the conductor. Just as you cannot pour a pint of water into your bath so that it stands up above the general level of the rest of the water, so you cannot keep a larger number of free electrons in one part of a circuit than there

is in the other parts, and, if you try, the electrons will start a movement round the circuit until they have distributed themselves evenly in all parts.

In short, if we can introduce at one point of our circuit a surplus of electrons, we will start

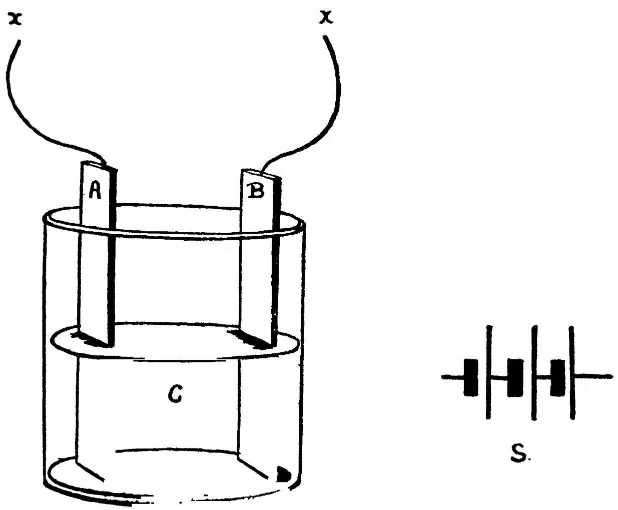


FIG. 6.—A voltaic cell. A is a piece of zinc, B a piece of copper, x, x copper wire, C water with a little acid in it. S is the conventional sign for a battery of three cells.

electrons moving all round the circuit until they have distributed themselves evenly from one end to the other.

Now look at the jar in the cupboard. It may or may not look like Fig. 6, but that makes no difference ; it works in exactly the same way.

It is what is called a cell, or if there are more than one of these jars, they are called a battery of cells.

Cells began with a frog's legs. On the continent of Europe they eat frogs' legs, but one day just before the French Revolution, one hundred and fifty years ago, an Italian doctor, named Galvani, did not eat a particular pair. He left it lying about near some electrical machines. As he was experimenting, suddenly the frog's legs jumped, in spite of having said good-bye to their head and body hours ago. Galvani began to play around with this new marvel and soon discovered that if he put a piece of iron to the nerve and a piece of copper to the muscle, directly he joined the two pieces of metal together, the legs jumped.

Ever since Galvani's day millions of frogs have lost their legs in the interest of science, and any science master will be happy to show you the dead frog-march that set Galvani thinking. It is hardly important at this late date that Galvani thought wrong, since another Italian, Volta, came along almost at once to set things right.

He showed that it was nothing peculiar about the frog's legs, but simply that when two different kinds of metal are joined in a circuit they produce a current of electrons, and that this current acted on the frog's nerve and muscle to produce a violent leg jerk.

Now it is of course very interesting that nerves and muscles should respond like this, and it gave a hint to later workers who have shown that our bodies work by the discharge of electrical currents along the nerves ; but what is of real importance to us to-day is this matter of the effect of putting two different metals in one circuit.

I have said that some metals have more free electrons moving about among their atoms than others, and this gives us a hint of what happened in Galvani's experiment. One of his pieces of metal had more free electrons than the other, and when a circuit was made they took the first opportunity to smooth out the difference.

Volta showed that this was so by putting a piece of zinc and a piece of copper in a bath of acid water and joining them with a wire, and that is what Fig. 6 shows. It will be worth your whilc to make a simple cell and see for yourself.

Buy a little sulphuric acid and put a few drops into a jam-jar full of water. Cut out a strip of zinc and another of copper and fix, preferably with solder, a piece of wire to each. Then hang these strips opposite one another in the water. I am afraid you will not be able to do anything very exciting with this simple cell because all sorts of things will make the current it generates very weak indeed ; but one thing at least you can do. You can cross the two ends of wire on your

tongue, when you will experience a peculiar taste which is not there if you taste one of the wires at a time. This taste, which only comes when a current is passing, will prove to you that you have really succeeded in making electrons move all round the circuit.

Now what has been happening? Let us think of the various ingredients of our cell, not as they

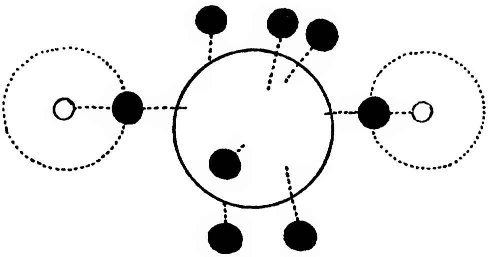


FIG. 7.—The central circle is the nucleus and inner electron rings of an oxygen atom. The black dots are eight electrons, six belonging to the oxygen atom, two forcibly shared with the hydrogen atoms drawn on each side.

look to our eyes, but in terms of their atoms and molecules.

First, we pour water into the jar and every molecule of water is made of two atoms of hydrogen and one of oxygen held together by a forcible sharing of their electrons. Here is a rough drawing of a molecule of water. You will understand the sketch fully if you remember what was said on page 24.

Next we put in a few drops of the sulphuric acid, the molecule of which is made up of

two atoms of hydrogen	called	H_2	for short
one atom of sulphur	called	S	for short
four atoms of oxygen	called	O_4	for short

$$H_2SO_4$$

The new atom, sulphur, is twice as heavy as oxygen and has sixteen electrons revolving round its nucleus, two in the first ring, then eight in the second and six in the last, where it would so much rather have eight. Somehow or other we must imagine these six atoms forcibly sharing one another's electrons and therefore sticking tight to one another ; just as the three atoms are doing in the picture of the water molecule.

Now when we put this molecule H_2SO_4 into the water it " dissolves " just as a lump of sugar dissolves in a cup of tea. It does not simply mix. If our eyes could see molecules, we should not see H_2SO_4 floating about like a big fish. It breaks up into three parts in a most important way. The two hydrogen atoms tear themselves away from the rest, and, in so doing, they leave their petticoat, their one electron, behind, and rush off, each a naked nucleus, consisting, as you will remember, of one lonely proton.

Meanwhile the third part of the molecule the

four oxygen atoms still clinging to the sulphur atoms keep, mixed up with them, the two electrons stolen from the hydrogen atoms.

In short, if we had eyes to see, we should find the harmless, satisfied H_2O, or water, molecules, suddenly invaded by a large number of dissatisfied, unbalanced strangers ; and what is more, some of the strangers are unbalanced in one way and the others are unbalanced in exactly the opposite. Some have protons without enough electrons, the others have too many electrons for their protons.

You might have expected the two sorts to make up their differences to their mutual benefit and come together again as the original balanced H_2SO_4 molecule, but for some reason or other, this never happens.

Now I want you to keep steadily in mind the strange thing that has happened while I take the opportunity to settle once and for all a ridiculous nuisance that we have to face sooner or later. It has to do with names.

What happens when sulphuric acid is dropped into water is written for short thus :

$$H_2SO_4 \rightarrow H^+ + H^+ + SO_4^{--}$$

and you may read it thus : " A sulphuric acid molecule becomes a hydrogen atom plus, with another hydrogen atom plus, with a sulphur atom

and four oxygen atoms two minus." And yet you know perfectly well that what has happened is that the molecule has become a hydrogen atom *minus* an electron, another hydrogen atom *minus* an electron, with SO_4 *plus* two electrons.

Why then do they put the little plus signs where it is minus an electron, and vice versa? It is due to a most annoying muddle.

Before anyone ever heard of electrons scientists saw that electricity, whatever it was, moved *from* some things *towards* other things. They decided that there were two kinds of electricity, one that repelled things, which they called negative electricity, and one that attracted, which they called positive electricity.

Of course, now we know that electricity is electrons moving away from any place where there are too many of them towards any place where there are too few. But, keeping the old mistaken names, we call an atom, which has too many electrons for its protons, a minus, or negative ion, and an atom, which has too few electrons for its protons, a plus or positive ion. (Ion is the name given to any unbalanced atom.) Further, a place in a circuit where there is a surplus of electrons is called the minus or negative point, and the place which has fewer is called the plus or positive point.

Of course, you would expect it to be the other

way round, but you will never be muddled so long as you remember that, whenever you see a minus sign in the drawing of a cell or circuit, it means that that is the point from which the surplus of electrons moves ; while a plus sign indicates the place to which the electrons will move.

And now we can get back to the exciting things happening in our cell.

III. HOW THE CELL IS A COOKING STOVE WHICH PRODUCES ELECTRIC POWER INSTEAD OF HEAT

We left the hungry positive hydrogen ions and the equally hungry negative SO_4 ions swimming in the H_2O. (If you had come across that sentence before you had read the last few pages you would have thrown away the book, but now you know exactly what it means.)

Now take a sheet of zinc and dip it into the solution in the jar. What happens ? You see a great many small bubbles coming away from the zinc, and if you leave it there long enough, you will find that the zinc is partly eaten away. Black mud falls to the bottom and little holes are eaten right through the plate.

Let us think of this in terms of atoms and electrons. The atom of zinc is twice as heavy as the sulphur atom and has thirty electrons rushing round a very complicated nucleus. The zinc atoms rush at the SO_4^{--} ions, knock off the two

electrons, and combine into a new compound called zinc sulphate, which you see falling to the bottom like mud. The zinc wastes away, losing atom after atom; the two electrons return to their long-lost hydrogen protons; and in the hurry and bustle all the molecules get banged and buffeted into a faster dance and so you see steam rising from your heated liquid.

But *now* comes the point to which we have been moving. If instead of simply putting a plate of zinc into the jar you put at the same time a plate of copper as well, something quite different happens. You do not see the zinc bubbling, there is no mud formed, the liquid does not get hot. Why?

When you drop the two plates of different metal into your solution, think of what Galvani and Volta found. We read about it a moment ago. There are more free electrons in some metals than in others, and particularly there are more free electrons in zinc than in copper. If you were to join these two plates there would be a momentary flow of electrons from the zinc to the copper, but as they are not touching there is no such flow. Now is the time to get quite clear about one of those important ideas that mean so much in science and are so helpful once we completely understand them, and are so muddling unless we do.

Often when one small boy is dared to do something by another, he will reply, "I could if I wanted to." If he is speaking the truth it means that he has the energy stored up in him all right, but does not want to use it just then. If he were one of those small boys who likes long words, he might say, "I've got the potential energy to do that but I will not use it just now." If the dare was to throw a ball at a policeman, he might even say, "I am not going at present to use my potential energy, to give kinetic energy to a ball."

When a thing has the power to do something, but is not using that power just then, it is said to have potential power or energy. A spring wound up has potential energy, which, when it is loosed, will be turned into kinetic energy, or energy coming from movement.

And so with the zinc plates; although there cannot be a movement of electrons from one to another until they are connected in a circuit, still there is already a *potential* between them. Directly they are joined with a piece of wire electrons will pass from the zinc plate to the copper plate because of the *difference of potential* between the zinc and the copper. And so the zinc is called the negative (that is the "away from") terminal, and the copper the positive (that is the "towards") terminal of the cell.

You will now see that, when you put both the

zinc and the copper plates into the solution at once, the *positive* hydrogen ions are attracted to the *negative* zinc plate, and the negative SO_4 ions are attracted towards the positive copper plate. The positive hydrogen ions would very much like to get some electrons from the zinc atoms and the negative SO_4 ions would very much like to get rid of their extra electrons to the copper atoms ; but nothing can happen because there is

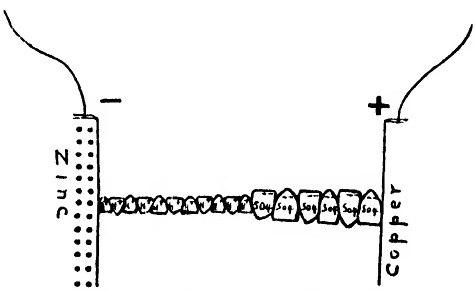


FIG. 8.—How the atoms of H_2SO_4 dissolve into ions and so form a pontoon bridge for electrons to cross. The black dots are surplus electrons anxious to cross.

no circuit for the electrons to move in ; *not yet.* No electrons are actually exchanged, but the hydrogen ions are all at the zinc end of the liquid and the negative ions at the copper end ; there they wait in readiness.

If you look at Fig. 8 you see that between the copper and the zinc there now lies a sort of pontoon bridge of ions, of unbalanced atoms and molecules, all able to pass electrons over from one

end to the other when the electrons are in a position to move. Also since the SO_4 ions have been attracted over to the copper end, the zinc atoms have no temptation to combine heatedly with the sulphur and oxygen atoms to make the muddy zinc sulphate. And now, with the help of a piece of copper wire, we join the zinc and copper plates ; a complete road is formed for the surplus free electrons at the zinc end to smooth themselves out evenly round the circuit. It is as if the small boy has decided to use his potential energy to throw the ball ; or as if the spring's " energy of being-wound-uppedness " changes to " energy of unwinding ". In short, the *potential difference* between the plates becomes an *electron moving force*, or, as it is called, an electro-motive force, or E.M.F. for short.

But this would last only for an instant ; in a flash the electrons would have distributed themselves and all would be over, if . . . what ? If the zinc did not seize the opportunity to begin to dissolve. As soon as the electrons begin to move, the zinc gets at the SO_4 and combines with it ; the chemical change sets free energy, but now instead of the energy being wasted in haphazard bangings into molecules, which make useless heat, it is used to keep the electrons moving round the circuit.

And so it all comes to this, that our jar is a sort

of cooking-stove burning zinc atoms and sulphuric acid molecules as fuel, but burning them in a way which, instead of producing motion of molecules, or heat, produces motion of electrons, or E.M.F. And this E.M.F. will be kept up so long as there is any fuel left to burn.

We now know what the cell's importance to the bell circuit is. It provides a continuous electromotive force, or E.M.F. How is this E.M.F. used to ring a bell?

IV. HOW WE LET DOWN A DRAWBRIDGE AND ALLOW ELECTRONS TO PASS OVER AND HOW THEY AT ONCE FORCE A PIECE OF IRON TO JUMP FORWARD AND RING THE BELL

Leaving the jar in the cupboard, we will make a tour of the circuit via the front door. Here is a picture of the bell-push. If you can do it without getting into trouble, unscrew the wooden front of the bell and see inside for yourself.

First, the button of bone or ivory probably comes away with the front, leaving to view a little spring. When you push the button down on the spring it acts as a bridge between two ends of wire. In fact, it is a drawbridge to be let down in order to complete the road along which the electrons are to move. When the drawbridge is up, the road is broken at this point, and so all along the wire, in the cell, in the bell unit, every-

thing is still. When you let the drawbridge down the potential at the zinc plate turns into electro-motive force; electrons hurry across the pontoon bridge, along the wire road; across the drawbridge; on along the wire road to the bell-unit; whither we will follow them.

Get a friend to press the bell-push while you

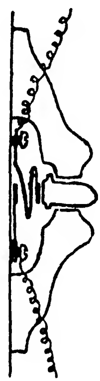


FIG. 9.—The drawbridge at your front door which is let down to allow electrons to pass.

watch the bell-unit. Directly the drawbridge is let down, you will see the piece of iron, to which the bell-clapper is joined, fly forward towards the reels covered with thin copper wire. Almost immediately the iron bar falls back again to its original position; once more it starts forward; falls back; and so on, so long as your friend pushes.

What is the force that pulls the bar forward to meet the reels ?

Try this simple experiment. Get your friend to stand at the front door and press the bell when you want him to. Take a loop of thread and with it hold the bell-clapper and the iron bar back so that they cannot come forward and touch the bell or the reels. With your other hand hold a needle threaded on a piece of silk near the ends of the reels. Now you are ready for your friend to ring. No sooner has he pressed down the button and so put the drawbridge in position than your needle flies towards the reels and sticks to them. Directly he lets the drawbridge up, the needle falls away. This will probably give you a suspicion of what goes on in the bell-unit. Everybody has at some time played with a magnet and seen a needle jump towards it.

But if there is a magnet in the reels, why does not the iron bar cling to it always, and what has electricity to do with it in any case ?

Your experiment gives you an answer to this. The needle did not spring forward to the reels until your friend by letting down the drawbridge allowed the electrons to move in the circuit. Even if you cannot pull an old bell to pieces, it is easy to see from the drawing that the wire wound round the reels is part of that circuit ; the wire from the front-door drawbridge comes in at the

point A, joins the lower reel at B, leaves it at C, and crosses to the other reel at D. After going round and round this reel it gets to E and thence through the pivot of the bar and clapper to F and finally out at G towards the jar in the cupboard.

It is possible then to put two and two together and say that while there is a movement of electrons round the two reels, the iron inside them becomes a magnet, and directly the electron movement ceases the iron ceases to be a magnet again. This is a very surprising fact, and in case you have been feeling that we are going far away from wireless in all this talk about bells, let me say that nobody can hope to understand wireless unless he knows a great deal about this electro-magnet, as it is called.

Before considering the way in which an electric current wound round a piece of iron turns it into a magnet let us finish exploring the bell-unit. Look at the point marked F. It will explain why the iron bar almost immediately falls back after having been attracted by the electromagnet. F is another drawbridge; when the bar goes forward to meet the magnet this drawbridge is pulled up and so stops the electrons from moving round the circuit.

At once the electromagnet ceases to be a magnet because there is no movement of electrons round the coils on the reels, and the spring-pivot of

the bar, no longer having to fight the power of the magnet, pulls the bar back to its original position.

But this lets the drawbridge down once more, the electrons move, the electromagnet is magnetized ; the bar goes forward ; the drawbridge goes up ; the bar falls back ; and so on very rapidly, until the whole process is stopped by your friend finally pulling up the other drawbridge at the front door.

There is now nothing that you do not understand about the working of an electric bell ; but what is much more important, you have a clear idea about how electrons move and how we put them to work. Let us look a little more closely at electromagnets.

V. OF THE INVISIBLE WORLD AROUND A MAGNET AND HOW IT CAN MAKE ELECTRONS MOVE IN A NEAR-BY PIECE OF WIRE

It was a hundred and fifteen years ago that two scientists, neither knowing what the other was doing, discovered that if you move electrons in a wire coiled round a piece of iron, you magnetize the iron. Soon afterwards Faraday made an equally surprising discovery. If you have a coil of wire and drop a magnet, as in Fig. 10, into the centre of it, you produce a momentary movement of electrons in the wire. The electrons move

only while the magnet is approaching the wire; they stop while the magnet is at rest, and move once more as the magnet is taken out.

Thus:

1. Electrons moving in a conductor magnetize iron near them.

FIG. 10.—A magnet dropped into a coil makes the electrons in the wire move.

2. A magnet moving near a conductor starts an electromotive force in the conductor.

So you see the magic amber and the magic stone from Magnesia join hands in modern electro-magnetism. Whenever electrons move there are magnetic forces, and whenever magnets move there are electric forces. Let us take a closer look at that stone from Magnesia.

Fig. 11 is a picture of the magnet we dropped into the wire coil in Fig. 10. It is an ordinary bar of magnetized steel or iron. Then why has the draughtsman put all those dotted lines around it? They are the invisible part of the magnet, which is just as real as if you could see or touch

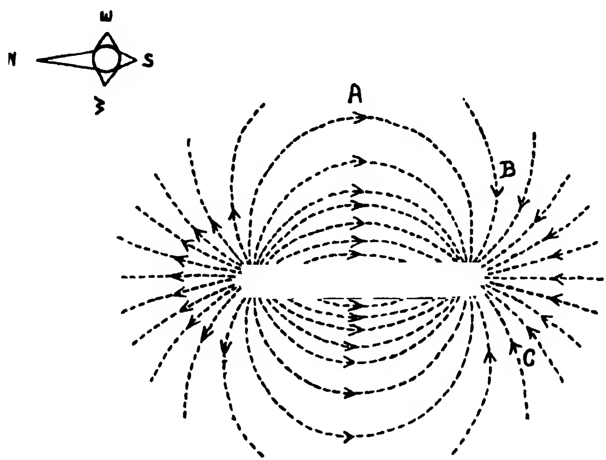


FIG. 11.—The invisible, untouchable part of a bar magnet, which is able to push and pull.

it. The lines represent a real part of the magnet, but a part which our bodies cannot discover because we have no sense to tell us of it. We must invent an instrument to show that it really exists.

In Fig. 12 we see a bar of ordinary unmagnetized iron and by its side the sort of needle that

is used in a compass. Everybody knows that a compass needle has been magnetized by rubbing it with a piece of magnetic iron ; and that it will always point towards the magnetic north pole of the earth. When the ancient heroes had sufficiently got over their surprise at the magical powers of the stone from Magnesia, this was the

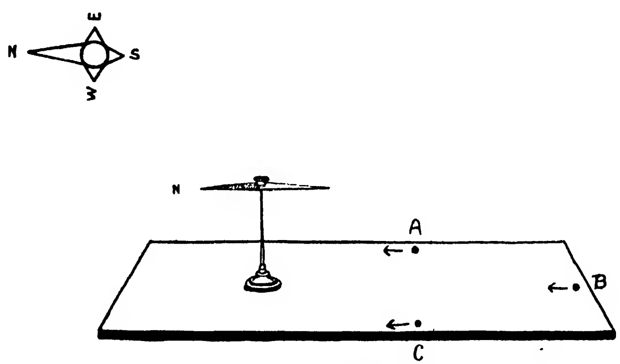


FIG. 12.—A bar which has not been magnetized. Compare the way a magnetic needle lies at A, B, or C, with the way it lies if it is put near the bar magnet in FIG. 11. In both figures the north pole is to the left of the drawing.

first way they learned to use it, to guide sailors on dark nights when the Pole Star could not be seen.

The compass needle will always point towards the north, which we are to suppose is in the direction of the arrow in the top left corner of the sketch. We may twist it and turn it, but always it will come to rest in this direction. And it will

not matter where we put it on the table or on what side of the bar it lies, at A or B or C for example, it will come to rest in the direction of the arrows.

But now put the compass needle near the magnetized bar. What happens? No longer does it point towards the north, but some invisible thing pushes it along the direction of the arrows marked on the dotted lines of Fig. 11. Put the compass at A or B or C and, instead of pointing to the north, the needle will be forced into the new directions indicated.

Suppose you are standing in the dark and you feel yourself forcibly turned round; you naturally assume that somebody or something, however invisible, exists to do the turning. And in the same way, we suppose that there must be an invisible magnetic field able to turn the needle.

Of what is this "magnetic field" made? Nobody really knows. We have to be content to study what it does. It does two very interesting things; first, it pushes at a compass needle, and second, when it is moved closer or farther away, it produces electron movements in conductors lying near.

But there is something else very important about magnetic fields. Fig. 13 A shows an electric wire piercing a card which has been put in a horizontal position. Near it on the card lies a

compass needle, pointing to the north. There is no current passing through the wire.

Next turn to B; a current has been switched on and the electrons are moving through the wire in the direction of the little arrow. What has happened to the compass needle? It has been pushed away from the north and forced to lie

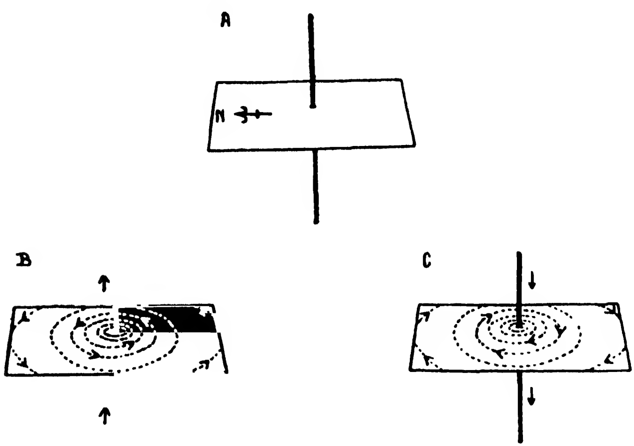


FIG. 13.—When electrons move through the wire, a magnetic needle lying on the card is pushed out of place.

in a new direction. Next we switch off the current and the needle returns to its usual position as in A. Now we turn the card upside down, so that this time when the current flows the electrons will be moving downwards as in C. This time the needle is pushed in the opposite direction. You will find no difficulty at all in doing all this for

yourself. If you take a compass and put it in different positions near the wire, you will find that it takes up the directions marked along the circles in B and C. The dot shows various positions of the needle and the arrow joined to the dot the direction in which it will point at that position.

In short, every conductor in which electrons are moving produces a magnetic field at right angles to the direction in which the electrons are moving. This field is made up of forces able to push sensitive things like compass needles; and is therefore as real as the conductor itself, although we are unable to see or touch them or know anything about them with the senses of our body.

Once more we are struck by the exciting fact that electricity is not just a matter of electrons moving along a wire, interesting enough as that is, but that in every direction, whenever electrons move, *things begin to happen* in an invisible world.

VI. HOW THE MOLECULES IN A MAGNET DIFFER FROM THOSE IN AN ORDINARY PIECE OF IRON

Let us think of the iron bar inside the reels of the bell-unit. What can have gone on inside it to change it from an unmagnetic to a magnetic piece of iron? The change has been made by the movement of electrons in the wire wound

round it. Now we know that when these electrons move through the wire they produce a magnetic field at right angles to the wire. We know that this field could push a compass needle away from the north. What has happened to that part of the field which must pass inside the iron core of the reel ? Let us once more think in terms of atoms and electrons.

The iron core is made up of billions of iron atoms and each of these atoms weighs fifty-six times as much as a hydrogen atom and has fifty-six protons and thirty electrons bound together in its nucleus, while twenty-six more electrons revolve around the nucleus.

Since last we talked of revolving electrons, we have learned a most important fact about all moving electrons : they produce a field of magnetic force around them. Very well, since there are moving electrons in every atom, every atom in this bar of iron is a tiny magnet.

Why then are not all bars of iron magnetic ? Why for that matter is not everything in the world magnetic, since everything is made of atoms with moving electrons ?

If you have a compass, take it and toss it carefully in the air as you would a penny, then look at the needle. It spins round in a bewildered fashion and takes quite a time to settle down in its proper north-south position. Yet the treatment

you have given it is infinitely gentle compared with what happens to all these atom-magnets, for they are knocked and twisted billions of times a second. No wonder they never have time to get into one and the same north-south alignment. You can imagine anything in the world as consisting of billions of atom-magnets all in the haphazard state your compass-needle got into when you tossed it in the air.

But when a powerful magnetic field comes along, like that made by the coils of copper wire, it is able to arrange all the atom-magnets so that they face in the same direction, and then instead of all cancelling out as usual, they pull together strongly enough for us to feel the results.

The effect only lasts while the magnetic forces from the moving electrons are there to control the atom-magnets. Immediately the cat goes away the mice begin to play, and what was a neat arrangement becomes a dancing bedlam.

Even so-called permanent magnets, such as the horseshoe magnets everybody has played with, lose the neat arrangement of their atoms unless you are careful how you handle them. You have only to throw such a magnet on the ground a few times to jar sufficient of the atoms out of their alignment to weaken the total magnetism quite a good deal. If you are so foolish as to speed up

the normal dance of the atoms by putting the magnet on the fire, all order will very soon be lost and you will discover that you have no longer got a magnet at all.

CHAPTER III

EYES: THE FIRST WIRELESS WAVE RECEIVER

I. JUMPING ELECTRONS; AND WHY A POKER GETS RED HOT; WHY THE SUN SHINES; AND WHERE THE ELECTRIC LIGHT COMES FROM

WE have seen how the movement of electrons has all sorts of exciting effects, not only in the copper wire along which they are moving, but far out into the world around. Let us now see what happens when an electron jumps from one path to another inside its atom.

We will begin with a red-hot poker. I do not know how it is with boys who live in America, where the family hearth has become a set of hot steam-pipes, but when I was a boy in England, I used to spend long hours, or at any rate long quarters of an hour, watching what happened to a poker thrust into a glowing fire. First hot, then red hot, then white hot. For hundreds of years it has fascinated all of us; the red-hot poker and the unkind use to which it is put by the clown in

Harlequinade is one of the oldest jokes in the world. Here is a new gag for the clown as his victim leaps away in agony. "Think of it in terms of atoms and electrons, my friend."

We will do well to take this piece of clownish advice. First, the poker gets hot; that means that all its atoms are being stirred to quicker and quicker movement. They are banging into one another more and more. They are getting farther away from each other so that the poker is expanding; but they are increasing the force of their battering.

Now look at what is happening in *that* atom, and in that, and that; the electrons are becoming so agitated by the rough treatment that they are leaping from one path to another. You cannot see them jump, at one instant they are in one place and at the next in another. Apparently they never have to spend any time over the journey. Heaven knows how they do it, but look at the result. Whenever an electron makes its leap it seems to send out a splash which spreads in all directions in space. . . . But wait a minute, it is no use *looking*, for you and I cannot look in the tiny world of atoms and electrons; our eyes are quite useless there, and we have to approach things in another way.

The poker gets red hot; the sun shines; so does an electric lamp; and a struck match—

light everywhere and always combined with heat. Let us begin again thinking it out in terms of atoms and electrons.

The poker gets red hot—the molecules of the gases and other fuels in the fire are chemically combining (sharing electrons) with the oxygen atoms in the air. This releases energy, which is used to jostle and bang one molecule against another until the speed gets faster and faster, and we feel it hotter and hotter. These violently dancing molecules stir up the iron atoms and the poker gets hot. Then the iron atoms get so badly banged about that their electrons jump from orbit to orbit. Result—red glowing light.

The sun shines—Another fire, but on a much larger scale. Battering molecules never leaving one another in peace. In all directions jangled atoms unable to control their electrons. Some get torn off altogether; others jump from orbit to orbit. Result—fierce heat and light.

An electric light shines—We have made electrons move along a wire. As they go they bang into molecules and the temperature all along the wire rises a certain small amount. But in one place in the circuit, in the light bulb, we have put a far thinner piece of wire, which we call the filament. The flow of electrons reaches this spot and finds itself forced into a narrow bottle-neck

of a road. Look at this picture (Fig. 14) of what happens to traffic when a main road suddenly narrows down—a traffic jam; cars have to stop or else there are accidents. Moving electrons prefer accidents to stopping. They rush the bottle-neck, hitting into molecules mercilessly. Faster and faster move the molecules; the filament gets hot, far hotter than the ordinary wire, so hot that the electrons begin jumping in each atom. Result—light.

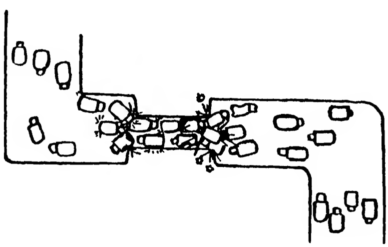


FIG. 14.—The fuse in an electric circuit is like a bottle-neck in a main road, it produces a traffic jam of electrons and molecules.

A struck match—You rub the match against the box, thereby speeding up a few billion molecules. The match-head is made of molecules that will immediately want to combine with the oxygen in the air, if they are hurried at all; and your scratch is enough for them. They start exchanging electrons and bang one another more and more in the process; once more the buffeted atoms find their electrons jumping their orbits. Result—light.

Light therefore, that first thing, without which we would not know that we existed, is due, just as much as an electric current, to moving electrons. The most interesting thing about it is that whereas the other things that happen when electrons move are invisible, we can *see* light. Why do we see this particular result of electron movement? Because it has suited nature to provide us with natural instruments to detect it, our eyes.

And what an amazing instrument the eye is. An electron jumps its orbit in an atom ninety-two million miles away in the sun and we *see* it. Every time our eye sees anything, even the light from a star a million times as far away as the sun, it means that electrons have been jumping their orbits in infinitely minute atoms, and that our eyes have been able to detect the jump right across empty oceans of space.

We will study this marvel carefully, because, believe it or not, the *eye was the first wireless receiving* set.

II. AN EXPERIMENT WITH TWO PING-PONG BALLS IN A BATH

A great deal has been thought out by men lying in their baths, which is a fact that parents do not always understand. We all know the story of the ancient scientist, who was seen one day running down the main street of his home town,

with nothing on him but drops of water, and they falling off him as he ran. As he ran, he cried: "Eureka, eureka; I've found it; I've found it." He had been lying in his bath which he had filled too full, and had suddenly noticed that, when his body got in, the water got out; and that, in a way, was the beginning of one branch of science. And so at your bath-time to-day take two ping-pong balls with you and float them a few inches from opposite ends of the bath.

Wait until the surface of the water is as still as possible. Then tap one ping-pong ball sharply so that it bobs up and down without shifting its position in the bath. What happens? A series of ripples leaves the edge of the ball in all directions. They travel down towards the other end of the bath and soon the other ball which has never been touched at all is bobbing up and down in exactly the same way as the first one.

Now, having watched this very simple experiment a few times, take the ping-pong balls out of the water and get on with your bath. I would like to be able to leave things at this point with you lying in the bath thinking them over. Indeed, if it is at all possible, please shut up this book now and go and have your bath with the ping-pong balls and think out carefully how and why the second ball moves. Ask yourself what happens to the first ball, what happens to the water, and

what happens to the second ball, which seems to move without being touched.

Obviously the first ball does not touch the second directly ; does it throw the bath water at it ? At first you may decide that it does. You may decide that, when you tap the first ball, it pushes the water at the second ; just as you can put out a candle without touching it by pushing or rather blowing the air in its direction.

But if you look carefully, you will see that this is not what has happened. Suppose before tapping the first ball you put, very gently, a drop of ink exactly half-way between the two balls and let it settle like a dark patch colouring the water half-way. If the tapped ball is pushing the water at the other and thereby moving it, you will be able to see the inky patch nearer the second ball at the end of the experiment than it was at the beginning. But if you are careful to tap the ball so that it just moves up and down you will find that the ink is where it was at first.

In fact the water has not been pushed towards the other ball ; nor has a drop moved its position ; and it is plain that somehow or other the tap you gave the first ball has been imparted to the second without any touching, pushing, blowing at all. And that is something you could not do to a lighted candle.

Now what you have done to these ping-pong

the right level. While this is going on anything that happens to be floating on the water is moved up and down when the ripple reaches it, but nothing is moved any nearer or farther from the first splash.

2. Air waves. In exactly the same way as water insists on keeping a flat surface, or getting back to a flat surface when it has been disturbed, the air insists upon being so spread out that there are exactly the same number of molecules throughout all parts of the space it occupies.

If in any way it comes about that there are a few billion more molecules in one cubic foot of air than in the next, the extra molecules will rush into the less occupied space in order to distribute themselves equally everywhere. But in so doing, they will overdo it. The first space becomes too thinly occupied and the second too thickly. Then the molecules in the second space will rush out on all sides, overdo it again, and overcrowd a third space next them; the overcrowded molecules in the third space . . . and so on in ever-increasing circles of too many, too few, until at last the air has settled down to an even distribution of molecules.

While this is happening it is not the air that moves forward, any more than the water does in a water wave; it is an ever-widening wave motion, passing on in all directions. If in its

course this series of air waves comes into touch with the drum of our ears, and if each wave follows the next at least as often as about sixteen times a second and not more often than ten thousand times a second, then our ear-drum ripples or quivers the same number of times a second and sends a message to the brain, which we call sound.

Of course there is no sound until the sound waves reach our ears. If living creatures had no ears, there would still be air waves, but the world would be an absolutely silent place. It is worth while remembering this.

3. The third kind of waves is those made, not in water, nor in air, but in *something else*, when electrons make a splash in that something else by jumping from one place to another, or otherwise disturbing their surroundings. These waves, spreading out in exactly the same way as other waves, from the original electron splash, reach our eyes, and if each wave follows the next the right number of times a second, they start electrons jumping in our eyes and the brain tells us of these electron jumps and we call it seeing.

But what is the something in which these waves move ?

IV. WHAT IS IT THAT THE JUMPING ATOMS SPLASH ?

For splashes to make waves it seems obvious that there must be something or other for them to make waves *in*. You cannot splash in an empty bath ; there must be air for a sound wave to reach your ears ; in what then do the electron-splash waves travel ? The answer is that nobody knows, and that the guesses are so complicated that very few people have much idea what they mean.

People used to say : " There must be something for these waves to travel in, but it cannot be air. For one thing there is no air in the depths of space through which these waves travel, and for another these waves travel altogether too fast. But this something must be very like air, only far finer and more delicately made. So let us call the unknown something ' Ether ', which is the Greek word for the upper rarified air beyond our common breathable air."

They called it Ether, and since they had invented it to explain how light waves were carried, they called it especially the Luminiferous Ether, which means " light carrying rarified air-like thing ". But the trouble is that no one has ever been able to prove that this luminiferous ether exists. It escapes every scientific detective that looks for it, and all we can honestly say is that if only it did exist, it would be very much easier

to understand how light waves travel from the sun or a star to our eyes.

It is as if we performed our experiment with the ping-pong balls in the bath without being able to see or touch or measure any bath water. If we saw that the second ball moved as if influenced by the first ball, we would say. "The bath looks empty but it behaves as if it were full of water, and so we will suppose there is water in it, until we have good reason to know that there is not."

In the same way with the whole universe, we say: "Space looks empty, but it behaves as if it were full of ether, and so let us suppose that there is ether filling all space."

But remember we know nothing about ether, not even that it exists; and we may be able some day to do without pretending that it is there. That has already happened to "gravitational ether", which people supposed must exist so that the sun could pull the earth through it with the force called gravitation. "You can't have a tug-of-war without a rope," people used to say; but Einstein came along and showed them how to think of things in another way, which did away with the need for this invention. The same may happen with the "luminiferous ether", and until it does do not allow yourself to be frightened by the long name.

V. HOW THE WORLD WOULD BE SILENT AND INVISIBLE IF THERE WERE NEITHER EYES NOR EARS

I wonder if you were struck by something I said at the end of § III: If there were no ears, it would be a silent world. To me it is a very exciting idea and it is good practice sometimes to imagine what the world must have been like before there was any living thing.

It was a silent place. Vast earthquakes blew up the sides of huge mountains, but there was no sound. There were air waves of course; the molecules of air got crowded up in one corner and immediately tried to get evenly distributed again, overdoing it many times until they succeeded. Then as now, when there was lightning there was also thunder; but it was silent thunder. And the lightning was invisible lightning, because nature had not produced any instrument to detect it. No ears existed to turn air waves into sound; no eyes existed to turn ether waves into light.

Try as you sit there to think of the noises you hear in terms of atoms and molecules. What was that? A motor-car passing. Yes and no. It was really a quivering wave of air molecules pulsating against your ear-drum at the rate of about forty or fifty a second. Long experience

tells you that the air waves began by some petrol igniting and exploding in the road outside and splashing the air so that its molecules got bunched up together at too close quarters.

The deep noises of traffic are air waves coming to your ears at a rate of thirty or forty or fifty a second ; the squeaky, high noises of insects, the creaking furniture, the tinkle of bells are air waves arriving perhaps two hundred times as frequently.

All started for the same sort of reason, something made a splash in the air ; and ripples, as on a pond, but of course in three dimensions, started out in all directions. All are heard for the same reason ; because they have made the drums of your ears vibrate an equal number of times per second as the waves started by the splash. No ears, no sound.

But not only was the world before life came soundless, it was, as we have said, invisible. Violent motion of molecules on the sun bashed and broke the atoms ; forced the electrons in them to jump from path to path ; and every time this happened, there was as an ether splash, from which there went to the ends of the universe ever-widening ether waves. But there was no light ; for light is what we call the effect in our brain of electrons in our eyes vibrating in tune with the oncoming ether waves, expanding from

a far-off ether splash. *No eyes existed to turn these ether waves into light.*

Then in this soundless and lightless universe something happened; one of the elements, carbon, got built up with other kinds of atoms into very complicated molecules indeed. These molecules stuck together in groups which we call cells. Many of these complicated molecules must have been too unbalanced to survive for long the terrific stress of jostling atoms and battling protons and electrons. But some managed to hang together and they began to behave in new ways. For instance, they took in atoms from the outside world and used them to build up ever more and more molecules within the cell. Then when the cell reached a certain size they split in two and each part went on exactly as before, only unhindered by any too unwieldy size.

We call these cells, made up of very complicated molecules, protoplasm; and the first lumps of protoplasm that stuck together, and grew bigger by swallowing atoms, and split in two and started over again, were the first living creatures.

And there was another thing that they did; they lived in water, and when things were not satisfactory for them in one place, they moved to another. How did they do it?

They certainly did not say to themselves, "This is a most uncomfortable and draughty

place, let us get a move on." They did not know they moved; they did not know how to move; they just moved because they were forced to move by things outside them; just as your chair moves because you move it.

What forced them to move? Among other things, the splashes made by jumping electrons in the atoms of the sun. Picture billions of these cells, living cells, in a shallow pool of water, shaded at one end and sunny at the other. They float as the wind and tide carries them. Presently they have floated from the shady part to the sunny part. Now among all these billions of cells, some will chance to have their atoms and molecules so arranged that the ether waves from the sun can make them vibrate, or make electrons jump about in them. This perhaps changes the balance of the atoms, and even the weight and shape of the cell as a whole, in such a way that it rolls, or turns, or swims back into the shade again.

Many other cells happen not to have their atoms arranged in this way and they float on in the sun. A few hours later the sun has dried up nearly all the water in the pool except for a few puddles at the shady end; the cells that were not turned back in response to the ether waves are left high and dry out of the water and shrivel up and die. Those that turned back survive in

the puddles. Later it rains ; they grow fat ; split in two and so start a new generation, all the members of which will have their atoms arranged so as to make them sensitive to ether splashes which cause the ether waves that we call light.

This is of course only one of the ways in which the first living beings became sensitive to light and it is probably far too simple a picture of what took millions of years to bring about ; but what is undoubtedly true is that very early it became of use to living things to respond to ether waves, and because those cells that did not respond died, those that survived became more and more sensitive as time went on.

Once it came about that to be sensitive to ether waves meant life, and to be unsensitive meant death, nature the great inventor was launched on the task which millions of years later produced that wonderful ether wave detector, the human eye.

VI. A WORM'S EYE VIEW OF THINGS ; THE WORM, THE EARLY BIRD, AND THE RISING SUN

You could not say that the tiny amœba, a single cell of naked protoplasm floating in the water, *saw* the ether wave from the far-off ether splash ; but it *felt* it ; that is to say, its atoms reacted to it and then the cell as a whole was helped to live.

In course of time living things became more and more complicated and had more and more different things to do. The first forms of life used their whole body, one cell as it was, to do everything, to eat, to move, to feel light, everything. But soon we find several cells tied together and each helping the others out in the labour of living. Instead of the one-celled animal, we find the many-celled animal. And now one set of cells did the catching of food, another the eating, another the getting rid of useless poisons, another the moving of the whole body from one place to another, and so on. And in this division of labour a few cells here and there had the task of responding to ether waves from the sun. No longer did the whole body feel these waves, but here and there all over the body were special patches of light-sensitive cells.

Other cells were joined together into a sort of telegraph or simple nervous system; and their duty was to see that the whole body responded to any important information coming from the cells whose duty it was to collect news about the outside world.

If the light-sensitive cells gave news of sunrise or sunset, of a passing rain-cloud or a strange shadow, the nerve cells saw that the other cells did whatever was their duty in the circumstances.

And those animals that got the important news quickest and responded to it in the best way had a better chance of growing up and having children than the others ; and those children took after their parents and had better and better senses and nerves.

Let us look at a very lowly animal which has however advanced a long way from the earliest days—the common earthworm. The worm has nothing that deserves the name of eyes, but it is highly important for him to distinguish between day and night. He must know at the first possible moment that it is daylight, in order to avoid the gobbling appetite of the early bird.

Those worms that are slow to notice the coming of daylight—that is the ether waves from the rising sun—get eaten up ; and so through millions of years the worms that have faulty ether wave receivers have been weeded out, leaving only those with good receivers to carry on the worm family.

The worm's ether wave receivers are sensitive cells placed at different points along its body at the surface of the skin. When electrons jump their orbits in atoms in the sun these " eyespots " register the fact ; and the nerves see to it that the worm is down its burrow in no time.

Now think of a common enough trio in any

garden, the rising sun, an early—and hungry—bird, and a worm; think of these in terms of atoms and electrons.

To begin with, the earth is turning round so that a very hot ball of violently excited atoms ninety-two million miles away comes above the horizon. This ball has been in such a state of jostling excitement for millions of years that its atoms have sent out ether waves throughout space incessantly, and there is no sign of their ceasing to do so for millions of years to come.

The particular ones that interest us this morning left the sun about nine minutes ago and came hurtling into our garden at the speed of 186,000 miles a second. They are coming at the rate, or frequency, of anything between 400 billion and 800 billion to the second.

Some of them fall on the lawn and the trees and are reflected into the bird's eyes, including some that fall on the sprawling bodies of the worms lying about outside their burrows. For millions of years the bird's ancestors have had practice in how to react to these ether waves when reflected in exactly the right way to spell out the word, or rather the thing "worm"; and so almost directly the electrons in the bird's eyes jumped in response to them, the bird jumped too.

But so did the worm! The worm did not see

a bird ; it does not know as we do that birds exist ; but for millions of years those worms that did not jump at the moment their sensitive cells felt the ether waves from the rising sun, simply ceased to exist. They " never knew what hit them ", or whether it was a bird or a garden mower, but that made no difference. Only the worms that reacted to the little electron changes in the atoms of their light-receiving cells kept on living.

VII. OUR VIEW OF THINGS IS MORE COMPLICATED THAN THE WORM'S BECAUSE WE USE A BETTER NATURAL WIRELESS SET. HOW A WIRELESS RECEIVING SET IS NOTHING MORE THAN AN ARTIFICIAL EYE FOR SEEING INVISIBLE LIGHT

It is very hard for us human beings to get a worm's eye view of things. It is so much easier for us to put ourselves in the worm's place and to imagine that the worm says to itself : " Hullo, there's the sun ; I must get away before that bird over there sees me." But that is as far from the worm's reality as it would be if we imagined the rising sun saying : " Now for a good five minutes sport, Mr. Moon ; I'm going to send off some ether waves and I'm prepared to bet on the bird this morning." The more you can think in terms of atoms and electrons, the more you will

succeed in getting the worm's eye view instead of your own.

The worm, thanks to its light-sensitive cells, distinguishes between night and day, sun and shadow, but that is all. How little that is compared with what we know through our eyes; and yet our eyes have grown and developed out of just such simple light-sensitive cells as the worm uses. All that has happened is that, thanks to millions of years of use, we have better ether wave receivers than the worm has. Let us consider the improvements.

First we can amplify, or strengthen, the ether waves. The worm's eyespots just registered any powerful ether wave coming from the sun; our eyes, with the help of lenses, focus the waves just as a burning glass does; and so we can register far weaker waves. Instead of just knowing the difference between daylight and dark, we are sensitive to all grades of light, and can see faint stars, or a far-off candle.

This has made it necessary to include in our receiving set a means of controlling the amount of ether waves we allow inside; for this purpose we have an iris or diaphragm to close up or open out the lens fully in accordance with the strength of the light. You can see this working very clearly in a cat's eye, for since the cat has to be able to tune its receiver to see mice in the faintest

possible light, it has to have suitable screens to protect its ether wave receiver from the midday sun.

In the second place, different atoms in our eyes are tuned to different ether wave lengths, so that we are able to distinguish one wave length from another, or, as we usually put it, to see different colours.

One colour differs from another simply in the frequency with which the waves reach our eyes; for example, the only difference between red and violet light is that the length of red light waves is such that 400 billion waves reach our eyes per second, while the length of violet light waves is such that 800 billion waves reach our eyes per second.

The red-looking ether waves are therefore twice as long as the violet-looking ones, measuring their length from crest to crest. Of course, you will see that no ether wave has any colour in itself; colour is the name we give to the sensation of registering the waves and varies according to their lengths.

To the worm it did not matter what length ether wave disturbed his receiving cells; red sky in the morning is a shepherd's warning, not a worm's, and so his receiver does not tune in certain lengths and distinguish them from others. But in our long experience we have learned to use such tuning, to find it helpful to living, and

so the human eye has become more and more sensitive to gradations of colour, that is, to different ether wave lengths.

Now it is very important to remember that these natural receivers of ether waves, whether the simple untunable cells of the worm, or the wonderfully contrived eyes of higher beings, complete with tuning apparatus, amplifiers, dimmers, safety switches and so on, were all manufactured by nature to detect the ether waves coming from electron splashes *in the sun.* It so happens that most of the waves that reach the surface of the earth from the sun are those that have a frequency of between 400 and 800 billion to the second, and that is why our eyes are tuned to receive only those wave lengths. Nature does not waste time inventing useless things, and so neither the worm's cells nor man's eye are sensitive to wave lengths outside the commonest that come from the sun. *But this does not mean that waves of other lengths, longer and shorter, do not exist.* We *see* only those lengths that nature found useful for us to see, and if we want to detect any other waves, we have to make our own detectors artificially.

And that is what all this comes to ; *the wireless set is an extra eye* invented by man to tune in ether waves that are too long for his natural eye to detect.

The only reason why we listen-in to the set instead of seeing with it, is because we find it convenient to mix up a telephone with it. But apart from the telephone the wireless set works on exactly the same principle as the worm's light spots or a man's eyes. The thing they all detect is the same, namely, an ether wave caused by a splash in the ether at a distance from them. The waves are exactly the same in both cases, except that they differ in length.

Try to realize that if you could retune your eyes so that they were sensitive to ether waves much longer than those to which nature has tuned them, you would see wireless waves as a sort of light.

It took men a long time after they first realized that light was a wave in ether before they discovered that there were any number of other ether waves invisible only because our eyes are not tuned to them. And when the discovery was made it was only after a long series of happy accidents seized on by brilliant minds and turned to good account.

CHAPTER IV

INVISIBLE FORCES AND UNEXPECTED SPARKS

I. A VERY SIMPLE EXPERIMENT, WHICH INTRODUCES US TO THE INVISIBLE FORCES THROWN OUT INTO SPACE BY FREE ELECTRONS

WHEN I was a small boy, I wanted very much to do scientific experiments ; but at school I had to spend long hours learning Latin and Greek and there was no time for anything else ; so I resolved to try on my own out of school.

I had no money and my occasional peeps into the school laboratory full of wonderfully blown glass and highly polished brass made me afraid that without wealth I could do nothing. At last one day I opened a little book on electricity. It said that it was going to describe some simple experiments in electrostatics, and the first picture was very much like the middle of the one you see at the beginning of this book.

This certainly looked simple enough, but, alas ! when I read I found that to do these experiments

I needed two or three "pith balls". I did not know what a pith ball was, and imagined that I should have to send to an expensive scientific instrument maker for them. I shut up the book and abandoned my study on the grounds of expense.

It never occurred to me that I could scrape a pellet of pith from the inside of any dry stem in the hedgerow, or that all sorts of other things might do just as well. I was worried by the fear that you could not learn science without expensive and complicated instruments. And that is why I have put this rather comical drawing at the beginning of the book, to encourage any reader who may have the same fears. The pith-ball experiment is surrounded by sketches of all that is really necessary for the moment in your private lab.

I myself am going to collect my apparatus this morning as follows : I shall get a cork from the rubbish-can ; a piece of pure silk thread from my wife's work-box ; my fountain pen from my pocket ; a narrow glass bottle, such as small quantities of olive oil are bought in, from the kitchen shelf ; my one and only silk handkerchief from my top drawer ; and as my trousers have wool in them, I make a mental note that they are on my legs and ready whenever I want them. I have all my apparatus, and, unless I tear my trousers, at no cost whatever.

With my finger-nail I nip off a small piece of cork and tie it to the end of the silk thread, and hang it from the mantelpiece. Next I take the fountain pen and rub it vigorously against my trousers, and then hold it very near the hanging piece of cork. As I do this I am probably more like an ancient Greek than I was when I tried to read a Greek sentence at school; for I am experimenting with the magical Elektron.

At first the cork seems to like the intrusion and bends its silk thread so as to touch the pen. Now, ever so gently, I shake the cork off the pen. With a leap that my gentle shake could never have given it, the cork jumps away; and now, however hard I try, I cannot induce it to touch the pen again. I chase it and it bends the silk in every direction so as to avoid a second kiss. Once bitten, twice shy, describes the cork's behaviour admirably.

I put the pen down and rub the glass bottle violently with the silk handkerchief. I tempt the cork with the glass. Off with the old and on with the new love with a vengeance. The cork willingly comes and embraces the rubbed glass.

What have I been doing? I have been doing exactly what the ancient Greek did with amber, and exactly what the English Dr. Gilbert did in 1600 with his "electrics". Let us think once more in terms of atoms and electrons.

II. THE ELECTRIC LINES OF FORCE WHICH SHOOT LIKE TENTACLES OUT OF ELECTRONS; AND HOW THEY BEND THE ETHER AND PUSH THINGS FROM THEIR PROPER PLACE

Cork, glass, vulcanite, wool, silk; we will not bother to describe the complicated atoms and molecules racing around in these apparently motionless objects. We will only think what happens to the electrons when we rub them.

First, we rub the vulcanite fountain pen against my trousers; the atoms in the woollen material get some of their electrons rubbed off and these electrons stick to the pen. We need not worry about the trousers, the robbed atoms soon collect more electrons out of my leg or from the chair on which I am sitting or out of the air; and unless I have torn away some whole atoms, I have not materially damaged my garments.

The pen is now covered with spare electrons, or, as we have learned to say, it is negatively charged. We take it and put it near the hanging cork. The cork moves towards the pen.

Now it would be very easy to make a rather serious mistake in explaining what has happened. It sounds easy to say that the hungry electrons are attracting the protons in the cork, with a view to both helping the other to get balanced up. But there are two reasons why this is a bad

way of explaining things. First, we do not know that there are any unbalanced protons in the cork; it is a neutral body, neither positively nor negatively charged. So why should the pen electrons hope to find lonely protons there?

Second, although it is true that electrons and protons attract one another, they can only do this from atom to atom; they cannot stretch out across a wide open space and move great masses of molecules in their desire to join one another. Whatever is happening to force the cork nearer the pen is even more mysterious.

I think we shall get a better idea of what this mystery may be, if we do our experiment in a slightly different way. We will first rub the pen against my trousers, so as to give it a charge of surplus electrons, then we will fix it up on end on the mantelpiece, using a drinking glass for the purpose. Now I bring the cork near the pen until it leaps against it. Next I gently detach the cork and it leaps away, and I cannot induce it to approach again. Something invisible keeps it at a distance and it waltzes round and round and cannot break through. It is really very surprising to watch this happening and I hope you are not just reading about it, but doing the experiments.

Clearly this invisible thing is very like the invisible part of the magnet we have already investigated. Just as we have discovered a field

of magnetic force round a magnet, so we have a field of electric force round a charged body. There are one or two ways in which we can get a picture of this invisible electrical field. We can

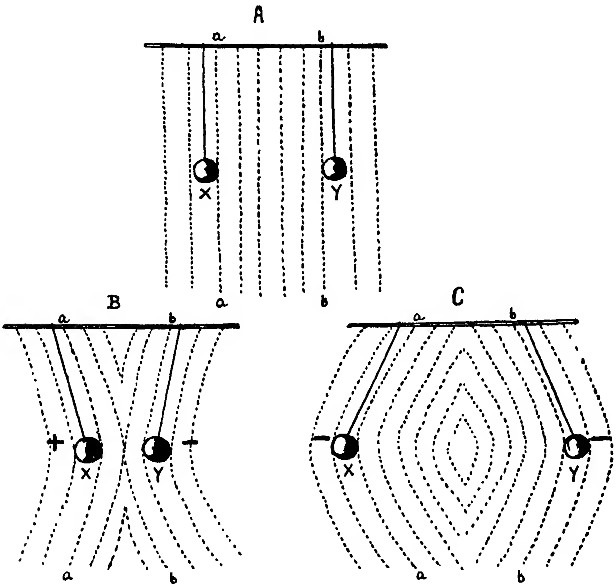


FIG. 16.—How the ether is bent by lines of force from electrically charged bodies.

say that wherever there are a crowd of free electrons, they have the power to bend the space around them, or to bend the "something" called ether that may fill space.

Look at Fig. 16; in A you see two corks hanging in space. They are neither of them

charged ; that is, they have more or less exactly balanced protons and electrons. Therefore they hang straight down on their silk threads. In the sketch the dotted lines are bits of the ether which fills all space, or so we think, *a*,*a*, is the strip of ether against which cork X lies, and *b*,*b*, is the strip against which cork Y lies.

Now we arrange to have cork X positively charged (that is, to have a surplus of unbalanced protons) ; and cork Y negatively charged (that is, with a surplus of unbalanced electrons). When two bodies with opposite charges are near one another, they move closer together ; why ? Because the ether gets bent ; instead of *a*,*a*, and *b*,*b*, being straight vertical lines, they are now strained into the shape you see them in Fig. 16B. But the corks must still lie against them, so that they take up the position we see them in in the second sketch.

Next we charge both the corks with the same kind of charge, negative or positive, it does not matter which ; and now the ether strain set up by the unbalanced protons and electrons is in the opposite direction ; *a*,*a*, and *b*,*b*, lie as in Fig. 16C, and still the corks must lie against them. This means that the corks are now farther away than usual.

That is one way of looking at things and a very good one, provided you do not forget that " ether " is nothing but a name for an unknown " may-be ".

We will now go back to our first simple experiment with the hanging cork and the negatively charged pen. As the pen approaches we can imagine the invisible field of electric force to be like Fig. 17; the lines are the lines of force going out in all directions and bending the ether. They are drawn longer at the end because in a body

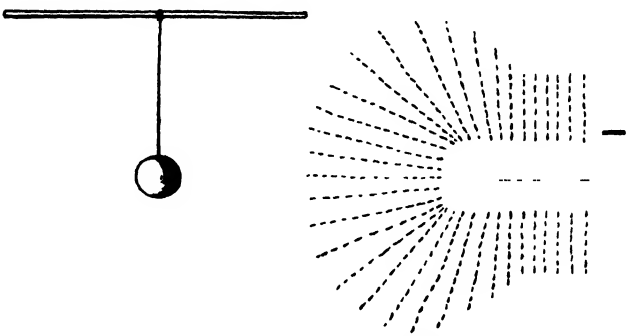


FIG. 17.—A charged fountain pen with its lines of force stretching out like tentacles.

shaped like my pen the charge gets concentrated at the ends.

As the pen approaches the cork, the lines of force go through the cork and come out on the other side as in Fig. 18. As they pass among the atoms in the cork they affect all the electrons they meet and drive a large number of them to the side away from the pen. We have put a plus and a minus on the cork to show this. It means that half the cork is positively charged and the other half negatively.

The pen comes still nearer and finally touches. The part of the cork it touches is made up of atoms all of which have had their electrons driven away by the lines of force, so that directly the cork and the pen touch, the surplus electrons in the pen rush over to fill up the gaps round the protons on the near side of the cork. All these atoms are thus balanced, and content ; but the

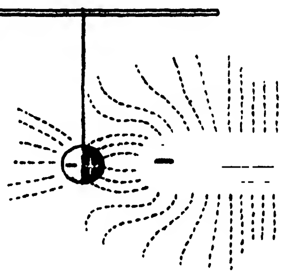


FIG. 18.—What happens when the pen reaches a body like a piece of hanging cork.

atoms on the other side have too many electrons, and when the cork leaps away from the pen, the surplus electrons distribute themselves evenly amid its atoms, and the whole cork is now negatively charged just as the pen is. The cork and pen being now both charged the same way distort the ether between them as in Fig. 16C.

There are several reasons why what we have seen is going to prove important, but above all there is this : you have seen how positively and

negatively charged bodies form fields of electric force round them and how directly the charges disappear the fields disappear likewise. (You have only to discharge two charged hanging corks by touching them with a wet finger to see how they at once begin to hang straight, however bent the silk thread was before.)

Now, whenever an electric field is collapsed and built up again very rapidly indeed the result is an ether splash from which waves go to all the ends of the world. But these ether waves are not the same length as those started when an electron jumps from one orbit to another inside the atom; they are much longer. They are indeed the length which we use when we send out wireless messages. Wireless waves come from the ether splash made by the collapse of the fields of electric force, which we have learned to know through these little experiments with cork and pen.

III. HOW LIGHT ITSELF TURNS OUT TO BE ELECTRICAL AND HOW A YOUNG MATHEMATICIAN NAMED CLERK MAXWELL PROPHESIED UNSEEABLE LIGHT. HOW MEN HAD ALREADY SEEN THE EFFECTS OF MAXWELL'S UNSEEABLE LIGHT, WITHOUT KNOWING IT

We have come farther along the way towards wireless than you may guess.

We know that electricity is the movement of electrons in a wire. We know that this movement sets up invisible but very real fields of force, magnetic and electric, in the ether round about. We have seen some of the ways in which these fields interfere with bodies close at hand. We also know that light itself is due to an electron splashing the ether as it jumps from one orbit to another within its atom. I confess that we learned this last fact rather easily by being told it. The world learned that light was an electromagnetic wave by a far harder road.

It was a little more than seventy years ago that a young mathematician named Clerk Maxwell showed by abstruse reasoning that light was electrical in nature. It had long been known that light moved in waves, but he proved that these waves were a kind of electromagnetic disturbance. He did not suggest how the disturbance started, but he realized that it had to do in some way with the strains and stresses round magnets and free electrons. Of course, he did not know what we know about electrons; they came later.

But this was only the beginning of Clerk Maxwell's work: he made a prophecy too. He said that some day there would be discovered other electromagnetic waves moving through the ether, differing from light only in their frequency and

length. These invisible unknown waves, he said, would all travel through the ether at the speed of light, that is 186,000 miles per second.

Those who were able to understand Maxwell's mathematics became convinced that he was right. Either there existed in nature these electromagnetic waves, about which we were ignorant simply because our eyes were not tuned to their frequency, or scientists could make them if they could discover the right apparatus not only for making them but for detecting them when they were made.

You can imagine how all over the world young scientists began to think out ways of trapping these waves. Invisible light! The idea was fascinating; but twenty-four years went by and invisible light was still invisible. "It is true," the scientists said, "that our eyes can only see ether waves of a certain length, and that, thanks to Maxwell's beautiful equations, we know that all sorts of other wave lengths may exist. But how are we to detect them? We can't see them, let alone hear, smell, taste or feel them."

And yet all this time, without anybody realizing it, people had been seeing the effects of some of these waves. Strange unexplained happenings in laboratories had puzzled one man here and another there and usually had been soon forgotten. In the city of Philadelphia in America, for example,

a man named Elihu Thomson was hard at work one day in his lab., proving that a colleague on the school staff was wrong. He was of course very happy in this good work and a little impatient with his apparatus. It did not seem to be strong enough for what he wanted to do ; so he looked around and found a water-pipe and a large metal still ; he put the latter on a glass jar and tied one terminal of his machine to it and the other to the water-pipe. I do not know if he meant to leave the room to find some paper to write down notes, or not, but just then, while the machine was working, he happened to take hold of the door-handle with a pencil in his hand. To his great surprise a tiny spark passed between the pencil point and the door handle. Apparently the electrical machine was producing some sort of electromagnetic disturbance that was making itself felt at a distance. If Thomson had put his pencil to part of the circuit he might have expected a spark ; but not at the door, which was in no way connected with the circuit.

Thomson ran upstairs into the Lecture Hall above and put the pencil point to various objects there ; again the mysterious sparks. He climbed to the third floor and drew sparks from the door of the mathematical professor's room. He continued his journey higher still and interrupted a colleague in the Observatory on the sixth floor.

Even here sparks proved that the machine six floors below was exerting some sort of influence, creating an electrical disturbance at a distance without the help of wires or other connections. Elihu Thomson thought about it for days; but in the end nothing came of it; he was a very busy man.

In 1879 an Englishman named Hughes, a really great scientist who invented the microphone, was working in a room in Great Portland Street in London. He was experimenting with microphones and other electrical appliances. As he worked he noticed that every time a spark passed through his machine a telephone on the other side of the room clicked. It was not conversation of course, but just the tell-tale click made by an earphone whenever it is electrically disturbed.

Hughes could not understand it. There was no reason as far as he could see why the phones should be affected. Leaving the electrical machine working, he strapped the earphones to his head and went outside into the street; he walked up and down and every now and then he heard the click that told him that the machine in his room was sparking. Five hundred yards up the street he still heard the signals. He even noticed that opposite certain buildings they were louder than elsewhere. But how did the telephone collect them from the sparking machine without any

connection with it? Hughes was listening to wireless waves.

And again it had been the merest accident; something had got loose in the machine connections and was sparking, just as you can see in your own house if you are careless enough to plug in a connection loosely. If you have a wireless set turned on near by, just listen to the clicks it will pick up.

Hughes was the sort of man who knew how to investigate such little accidents and he wrote to certain bigwigs of the Royal Society and asked them to come and see his experiments. He told them he thought he had got hold of Clerk Maxwell's invisible light. They came and listened and watched for hours and then said they did not think there was anything new in what Hughes had to show them. "I was so discouraged," wrote Hughes in his diary, "at being unable to convince them of the truth of these aerial electric waves, that I actually refused to write a paper on the subject until I was better prepared to demonstrate the existence of these waves." And there the matter dropped.

And yet exactly a hundred years before the visit of the bigwigs to poor Professor Hughes, a scientist, named Adams, had actually published an "Essay on Electricity", in which, though nobody noticed the importance of it until long

after, he described for the first time how wireless waves could be produced and detected. If Hughes and Thomson and the other experimenters had known of Adams and his work and had put two and two together, the mystery of these stray clicks and sparks would perhaps have been cleared up.

Let us turn back therefore to 1780; eighty-four years before Clerk Maxwell said there must be wirless waves, a hundred years before the bigwigs refused to believe in the waves when they were shown them, and a hundred and eight years before Hertz actually proved their existence by producing them.

IV. HOW TWO MEN TRIED TO PUT ELECTRICITY INTO A BOTTLE; AND OF THE SHOCK THAT THEY GOT. AND HOW THE SHOCK WAS DISCUSSED ALL OVER THE WORLD. AND HOW THE AUTHOR GOT THE SAME SHOCK, BUT TWO HUNDRED YEARS TOO LATE FOR IT TO BE IMPORTANT

I have a tender feeling for this part of my story because of a personal matter. It has to do with a professor named Musschenbroek and his pupil Cuneus who lived in Leyden two hundred years ago and they had a little accident very much like one that happened to me nearly two hundred years later. My accident led to the discovery of the

Leyden Jar, a discovery only important to myself since the world had known all about it for generations thanks to the two gentlemen of Leyden.

It happened to me like this : I had an aunt, who never liked me very much ; but in spite of this she gave me once a very handsome present, an electrical machine called a Wimshurst machine. She wanted to help a schoolmaster, so, you see, she was a rather uncommon sort of person, and the only way she could help him was to buy his Wimshurst machine, and the only person on whom she could dump what was totally useless to herself, was me. It arrived, broken in pieces.

I had never heard of a Wimshurst machine, but I could do jigsaw puzzles and after a number of false starts I got it together again in the right order. I knew when I had solved the puzzle, because it suddenly gave out a curious swishing noise and a moment or so later bright sparks passed between two brass balls. Having reconstructed it, I could not see any use I could put it to. I amused myself with getting sparks from the balls to various bits of metal in my bedroom and then I turned my attention to a curious thing like a flower-pot that had come in the box with the machine. It was made of glass and coated on the inside and the outside half-way up with thin

metal plates. There was also a little brass tripod ending in a ball which seemed to fit inside, and the whole thing looked like Fig. 19.

For want of anything better to do I held the knob of this object against the Wimshurst machine and turned the handle to watch the sparks. This is what I did (Fig. 20). The plates of the machine

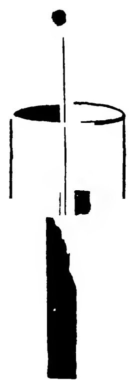


FIG. 19.—This jar is made of glass with a lining of metal and a coating of metal outside the glass. The knob and rod lead down to touch the inner coating.

revolved in different directions and sparks passed between the two balls *a* and *b*. Just then my mother called me to come and finish my home-work.

Two hours later my Latin was done and it was bedtime. My mother told me to go and clear up my mess. I picked up the thing likè a flower-pot

and took hold of the brass knob intending to pull the little tripod out. I was very surprised at the result, for I found myself sitting on the floor, feeling as if somebody had got inside my arm and turned the whole of it to a " funny-bone " and pinched it. I had discovered the Leyden Jar, and

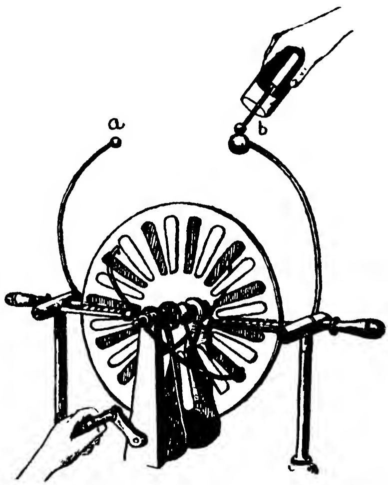


FIG. 20.—The adventure of the Wimshurst Machine.

the whole principle of the electric condenser quite independently of Cuneus and Musschenbroek, but a little too late in time to make it worth while writing to the papers. The only difference between the two discoveries is that whereas I was fiddling around with electrical apparatus with no idea as to what I was doing, they were fiddling around with a wrong idea.

They thought that electricity was a kind of fluid, a very thin kind of fluid of course, but still something that behaved like water, or tea, or milk; just as ether is regarded as a thin sort of air. And so they naturally thought that electricity could be poured into a bottle and they resolved to bottle it. They got an ordinary glass bottle and fitted it with a cork and half filled it with water.

To encourage the electricity to flow down into the water they pierced the cork with an ordinary nail so that it hung down into the water rather like the glass dropper in a medicine bottle.

Next they held the end of the nail to the knob of an electrical machine, just as I did, and turned on the tap, as it were. But the bottle refused to fill up, at least with any more liquid. And yet did nothing go into it? A little while later Cuneus took hold of the nail with his other hand and got an electric shock. Presently all Europe and America was talking of what had happened. The bottle became famous, and as this had taken place at Leyden in Germany, the world has talked of Leyden Jars ever since.

We are going to look very closely at the Leyden Jar, because in a way it is the link between the very simple electrical experiment shown in Fig. 18 and the transmitter that sends out wireless waves. Remember that when Adams in 1780 described

the first wireless experiment, he was using a Leyden Jar. Without the rather foolish experiment of the two gentlemen of Leyden, who tried to pour electricity into a bottle, we could not have made moving electrons the wonderful slaves to mankind that they are to-day.

V. A FOUNTAIN PEN AND A CORK COMPARED WITH A GLASS JAR WITH METAL PLATES INSIDE AND OUTSIDE. HOW THIS JAR IS A SIMPLE WIRELESS TRANSMITTER

Look back at Fig. 17 and Fig. 18. The pen full of surplus electrons (that is, charged negatively) approaches the cork, throwing out in all directions lines of force which bend the ether. These lines of force passing through the cork push away electrons from the near side and so positively charge that side and negatively charge the far side of the cork. We are now going to fix the cork by a needle to the ground instead of hanging it from a thread; this prevents it being pushed away from the pen later by the distortion of the ether; and it also provides a path for the electrons banished to the far side of the cork to run away into the ground.

Look at Fig. 21, you see what happens; the pen advances and the lines of force from the free electrons push away the cork electrons. But now they need not remain on the far side; they can

vanish into the ground, down the needle. This is a most important point to remember ; whenever there are too many electrons in a conductor, directly they are given a path to the earth they

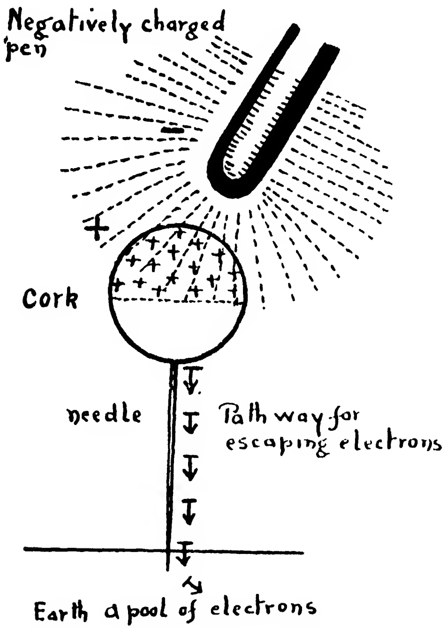


FIG. 21.—The earth is a reservoir of electrons into which we can pour as many as we like.

run away into the earth as into a big pool ; and whenever there are a number of unbalanced protons in a conductor, they are able to pull up from the pool of electrons in the earth enough electrons to balance themselves. In short, a

charged body discharges into the earth whenever it is joined to the earth. That of course is why telegraph wires are carried on insulators ; because otherwise the electrons we cause to move along them would run away into the earth down the telegraph poles.

In this figure the cork is " earthed " and the pen moves forward to touch it. Before the moment of contact we disconnect the cork, now positively charged, from the earth, and then as the cork and pen touch one another a feeble current passes from one to the other and the two little charges cancel out. That current or electromotive force or E.M.F. was due to the Potential Difference or P.D. between the cork and the pen when they met. You know too much now to be frightened by these long words. Now what we want to do is to use the E.M.F. for a useful purpose ; but this E.M.F. passing from pen to cork is altogether too small to be of any use to anyone. Can we make it any bigger ? Yes.

Imagine Fig. 21, with the cork as before stuck on a needle (in other words, earthed) ; but the pen now joined to some sort of electrical machine able to fill it with more and more electrons. The electrons are made to move down a wire to the pen and they accumulate there. The more electrons accumulate there, the more their lines of force working across the gap push

the electrons in the cork away, and send them hurrying away down the needle into the earth. Thus as long as the machine sends more electrons into the pen the Potential Difference between the cork and the pen gets bigger and bigger. Billions and billions of straining electrons gather on the pen, billions and billions of straining protons gather on the cork. These unbalanced hosts look at one another, so to speak, across the chasm, and long to jump ; but of course they cannot.

Now we disconnect the cork from the earth and the pen from the machine and touch the two together. Immediately a rush of electrons takes place and the protons and electrons balance one another. But, and this is the thing to remember, the rush of electrons is much greater this time because we raised the P.D. between the cork and the pen, and obviously the more P.D. the more current.

So what we have been doing is to show how two conductors between which there would have been a very feeble and useless current can be made to have a much bigger and perhaps therefore a usable current sent along them when they are joined.

Of course nobody would be so stupid as to try and do this with a cork and a pen ; there are much more practicable ways of doing it ; but what we have said will make it quite clear how the P.D. between two parts of a circuit can be

raised so as to get a sizable current instead of a very weak one.

A Leyden Jar is nothing else but a suitable way of doing what we have just described. Look back at Fig. 19; the inside metal coat to which the brass tripod ending in the knob is joined, represents the pen we have been using; the outside coat is the cork; the glass between is the space separating the cork and the pen. I touch the brass knob to a Wimshurst machine and thus fill the inner coat with surplus electrons; their lines of force act through the glass and push the electrons from the protons on the near side of the outer coat, and the electrons go down my arm and through my body and out into the floors and walls of the room. All this is exactly what we have seen, and the result is the same, namely, the establishing of a Potential Difference this time between the outer and inner coats, so that when these coats are joined more electrons will seize the opportunity to rush round the circuit and become evenly distributed. That is why I got a shock and why Cuneus got a shock when we joined the plates of our Leyden Jars through our bodies. A big E.M.F. rushed through and disturbed the peace of our nerves and muscles. Remember that if you hold, let us say, a piece of copper in one hand and of zinc in the other, and touch one with the other, electrons will pass, but

very few compared with when you use a *condenser* to increase the P.D.

This power that a Leyden Jar has of increasing the P.D. between two parts of a circuit leads to it being called a *condenser* ; and when you hear of there being a condenser in a circuit you will at once understand that in some way steps have been taken to increase the E.M.F. that can be got out of that circuit ; and you will see that a condenser increases the capacity of a circuit to do electrical work. And to this very important fact we shall be returning later.

Now suppose you discharge a Leyden Jar by holding it in one hand and putting your knuckles very near the brass ball, or in some safer way, you will see a little spark pass and at the same time hear a crisp crackling sound. If you can do so, will you please discharge a Leyden Jar close to a radio set that is switched on. You will hear a noise in your wireless set at the moment that the spark passes. You will be repeating the experience of which Adams spoke in 1780 ; which puzzled Elihu Thomson in Philadelphia in 1877, and Hughes in London in 1879. For the Leyden Jar and your body are acting as a wireless transmission station and you are sending out ether waves which your receiving set is picking up. And so the Leyden Jar has brought us right into the middle of things.

VI. THE TWO DIFFERENT WAYS THAT ELECTRONS MOVE TO PRODUCE ELECTRICITY. THE MEANING OF A.C. AND D.C. HOW A LAMP FILAMENT AND A FUSE DO THEIR WORK AND WHAT IS MEANT BY RESISTANCE. ALSO A NOTE ABOUT A ROW OF NINEPINS CONSIDERED AS AN INSTRUMENT OF TORTURE

The special way in which electrons move when a Leyden Jar is discharging is the cause of the ether splash that sends out wireless ether waves. What is this special way? And for that matter, how do they move in any circuit?

I wonder if you have formed a picture of a current in a copper wire and how it passes along. We have already seen that the early scientists supposed that electricity was a liquid; that is why to this day we talk of a *current* and say that it *flows*. They thought of the copper wire as a sort of pipe; they even talked of two different sorts of *fluid*, the negative and the positive; but we know too well to be misled by these words any longer, although it is convenient to use them. "Not much *juice*," says the man examining our wireless batteries, or the batteries of our motor-car.

Then do you think of an army of electrons rushing round the circuit, rather as grains of salt run when we turn a salt-cellar upside down?

Do you see a heavily loaded bus full of joy-riding electrons speeding round the copper circuit and over the drawbridges and the pontoon bridges? What would be more natural? But this is a wrong picture.

The electrons do not move very far along the wire individually; indeed I doubt if any electron ever gets more than two or three atoms away from its starting-point. Each atom does its share in producing the current by making the next electron move in a certain direction; it jumps from one atom to the next and there displaces a second electron which rushes to the next atom and so on all along the route.

In a piece of copper wire, as we have seen, it is easy for an electron to move from one atom to the next because the erratic path taken by some electrons makes it very easy for them to be torn from their mother's apron strings; but when this happens the freed electrons do not set out to see the world, they tie themselves up to the nearest foster-mother as soon as they possibly can.

Perhaps the easier way to get a simple picture of how electrons move when a current is flowing through a conductor is to think of a row of nine-pins, like those in Fig. 22. Suppose you were to give the row a sharp tap at A; the first ninepin would move over and tap the second and then move back and settle again in its own place; the

second ninepin would pass the tap on to the third and so on all down the line. In the end the last ninepin would be made to tremble without any of the others being moved out of their original positions.

Now imagine these taps coming millions of times a second and you have a picture of what is called a direct current or D.C. Between every tap each ninepin straightens up, so that it does not fall over ; it is then ready to pass on a suc-

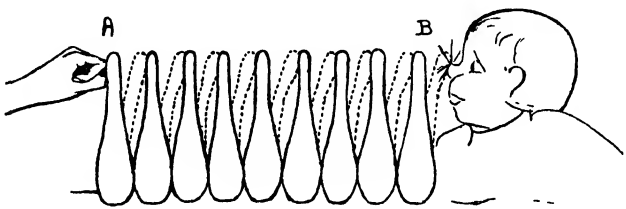


FIG. 22.—Bad dream of direct current used as an instrument of torture.

cession of blows, and if you put against the last ninepin some kind of machine which can use the blows you might imagine turning the whole thing to a practical advantage. You could, for example, hit somebody on the head with the ninth ninepin without yourself touching any but the first. I do not think that anyone would ever choose this way of doing it, but you will see what I mean.

Our row of ninepins may be a poor sort of mechanical contrivance but it gives us a clear idea

of some other facts about the movements of electrons. For example, you will see that although each ninepin passes on the original tap to the next, the tap which reaches the last ninepin is a good deal weaker. All along the line there has been a waste of energy ; one ninepin slipped a bit on the floor ; another was not quite touching its neighbour ; the floor was sticky underneath a third ; all sorts of things wasted or dissipated the force of the original tap. Let us call this wasting the *resistance* of the row of ninepins to the force going along it. In exactly the same way a circuit has a resistance to the electromotive force, applied to it.

This resistance varies according to certain very important rules. For instance, you will see that if instead of nine ninepins there were a hundred in the row, far less of the original force would reach the hundredth.

In the same way in a circuit of copper wire, the longer the wire the greater the resistance to the current. More of this force will be wasted banging into molecules and producing useless motion of molecules, or heat.

Every conductor offers resistance to the current according to its thickness. A thick piece of wire will have a lower resistance than a thin one, because there will be more paths between one molecule and another for the electrons to pass along. We make use of this last fact in various

ways, one of which we have already considered,—the filament in an electric light bulb. Another very interesting way which everybody knows is the fuse.

In the lamp filament we increase the resistance by putting into the circuit a very thin piece of wire, but we take care to use a metal the molecules of which can stand a great deal of banging about without running away from one another altogether, or *melting* as we call this loosening up of molecules when it is due to heat. Long before that happens in this kind of metal the motion of molecules is making the electrons jump their orbits within their own atoms ; and that, as we have seen, means the ether splashes which cause light.

With the fuse our object is different ; we do not want electron splashes, we want molecular running away, or melting ; and so we use another kind of metal which melts quickly under the strain of molecular bangings. When the electrons move through this, there is so much resistance that the fuse-wire gets hot, melts and so breaks the circuit ; and among other things all the lights in the house go out.

What is the use of the fuse ? The more E.M.F. there is in a circuit the more the molecules are banged and the hotter the wire becomes. Suppose we overload our lighting circuit, by putting in it

some apparatus that takes too much current, a badly made stove for example ; we shall perhaps heat the wire red hot, and a wooden wall or ceiling touching it will catch fire and the house be burned down. To avoid all danger of this we make the current pass through a fuse where the resistance will melt the wire long before any other part of the circuit gets red hot, and so when the E.M.F. is banging the molecules of the circuit too much for safety the circuit is broken in a safe place.

Now let us go back to our row of ninepins. Suppose instead of a person giving them pushes at one end only, two people pushed alternately at each end. You could still use the pushes to do work if you put something up against the last ninepin. There would be no advantage over the last method, if you simply wanted to hit someone on the head, but no doubt if you arranged your apparatus suitably you could alternately hit your friend and pull his hair with the last ninepin. I do not suggest, however, that a row of ninepins could ever be used as a really efficient instrument of torture, but it will give a simple picture of another sort of motion of electrons in a circuit.

It might be better perhaps to change the picture by imagining that we tie a series of loops round the necks of the ninepins, each loop threaded through the next one, and the last one at A joined to a piece of string as in Fig. 23. Now we tap

the first ninepin and pull the string alternately; each tap will pass along the line to the last ninepin as before, and in between each tap the jerk on the string will also pass along the line and move the last ninepin in the opposite direction, setting up a rocking all along, and moving each ninepin first one way then the other, but leaving them all in exactly the same place in the end. Once more work could be done on the proper machine if it were put at B.

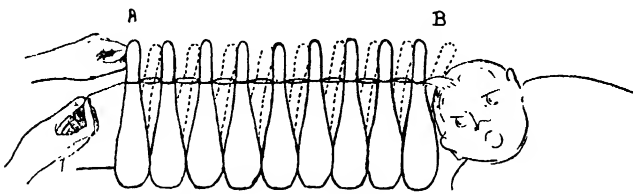


FIG. 23.—Another bad dream: alternating current used as instrument of torture.

Imagine these alternating pulls and taps coming a hundred times a second, and instead of a row of ninepins an electric circuit, and you have a picture of what is called an alternating current. It is produced by a machine that makes a point in the circuit alternately rich in surplus electrons and poor in electrons. How this is done is of no importance to us at the moment, but it is of the greatest importance that we should be able to picture the motion of electrons in an alternating current.

Look at Fig. 24; at the point X it is possible to introduce a huge number of electrons at one moment and to take away a large number at the next. Y is the usual sign for a condenser, like a Leyden Jar, *a* and *b* are the two plates of a condenser. The circuit goes on to Z where it joins the earth. The little lines narrowing towards the

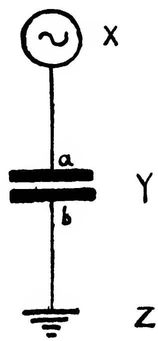


FIG. 24.—An alternator, a condenser and an earth.

bottom are the usual sign to show that a circuit is "earthed" at that point.

When the point X is rich in electrons the top plate of the condenser becomes rich also, that is, negatively charged. This causes the condenser to push down an equal number of electrons into the earth so that the lower plate, *b*, is positively charged to balance the negative charge on *a*.

Next moment X is made poor in electrons, that is, X is positively charged; the condenser plate

a becomes correspondingly poor and draws up an equal number of electrons from the lower plate *b* from the earth again. This happens perhaps fifty times a second and perhaps millions of times a second; electrons rushing now one way, now the other.

Consider two different things about this; first, no electrons can get across from *a* to *b*, and yet the *current* can get across if it is an alternating current. We shall return to this, but try to get quite clear on this point for yourself. Second, by looking at Fig. 13, remind yourself about what happens round a wire through which electrons are moving, and picture to yourself the state of the surrounding ether when the current, as here, is changing its direction anything up to millions of times a second.

VII. THE NEW THING THAT HAPPENS TO ELECTRO-MAGNETIC FIELDS WHEN THEY ARE FORMED AND COLLAPSED MILLIONS OF TIMES A SECOND BY ELECTRONS CHANGING THEIR DIRECTION

In Fig. 13, we saw how a compass needle is pushed about by the magnetic forces round a wire through which electrons are moving. If the current goes one way, the needle is pushed as we see in B; if the other, as in C.

We know that these pushes are due to strains in the ether caused by lines of magnetic force

shot out from the moving electrons. When the electrons stop moving, or, as we say, the current is turned off, these lines of force go back to the wire, rather as a snail withdraws its horns or a sea anemone its tentacles.

We have also seen that there are two kinds of stresses caused by every free moving electron; first the lines of electric force that we studied in Fig. 17, and elsewhere, and second the magnetic lines of force. The first stick out like spines from the electron and the second wrap the moving electron round in a series of circles. The magnetic lines of force are always at right angles to the motion of the electrons and at right angles to the electric lines of force.

Now imagine an alternating current passing through a wire. At first the needle will point as in A; soon the current gathers strength and moves in one direction; the needle now points as in B. Then the current dies down to nothing and the needle lies as in A again. Next the current grows in the opposite direction and the needle is as in C. Once more the current dies away and the needle is back as at A. A-B-A-C-A-B-A-C-A and so on very rapidly so long as the alternating current lasts.

The needle is of course simply used to show that the invisible magnetic field is there. Forget the compass and try to picture the electromagnetic

fields as they exist round an alternating current. Every time the current changes the ether is bent, straightened out, bent, in the opposite direction and straightened out once more. Just as Fig. 13 gives you an idea of what happens to the magnetic part of the field, Fig. 16 will give you an idea of what is happening to the electric part. It is as if the lines *a,a*, and *b,b*, were being distorted rapidly in opposite directions.

So long as the alternating currents are not changing very rapidly, say only a few hundred times a second, nothing very much happens that is new. The ether strains may grow, die down, grow in the opposite way and die down for some distance round, but that is all. And if that were the whole story there would be no wireless, and Adams, Thomson and Hughes would not have been puzzled by strange signals, sparks and clicks. *But*, when the alternating current changes a few million times a second, something quite new comes into the picture.

Instead of all the energy of the magnetic fields returning into the conductor, some of it gets caught up in the surrounding ether and never returns at all. It goes rippling outwards into the ether in ever-widening circles. And that is how wireless waves come to exist.

I think you were puzzled by the sentence: " instead of all the energy of the electromagnetic

fields returning . . ." What does this mean? Well, the magnetic lines of force can evidently do work. They can move a compass needle out of its usual line for example. Now it is an important rule of science that work cannot be done without spending energy on it; so it is plain that the fields of force have energy because they can do work. And if they have no work to do their energy goes back into the electrons when the fields collapse. But when the fields collapse very fast, not all the energy goes back; some of it is used in disturbing the ether.

It is really very simple. Think of yourself riding a bicycle along a mile of road. Why does it take more energy to ride on a rusty, ill-kept bicycle than on a clean, oiled one? Because you are using more energy in overcoming friction. If you were to feel the axles of the two machines at the end of a ride, the rusty one would be far hotter. You have dissipated a part of your energy in uselessly stirring up the molecules that make up the axle, instead of spending it all on usefully moving the bicycle as a whole.

In the same way when the electromagnetic fields collapse and reform very quickly, some of their energy is dissipated in splashing the ether and never returns to the circuit any more. They not only bend the ether back and forth but they make it wobble like a jelly on a plate, and this wobbling

is what we call in politer circles electromagnetic wireless waves.

The reason why Hughes, Thomson and Adams all stumbled on the effects of wireless waves without knowing it was because all three happened to be working with machines that produced rapidly alternating currents, or oscillations as they are called. Everywhere in the world machines were producing such currents, so that sooner or later somebody was bound to stumble on them. But one man acting on the hints that came from Clerk Maxwell's mathematical brain was able to arrange experiments so brilliantly that he could both produce and detect the waves, not by accident, but when he desired to do so.

That man was Heinrich Hertz, the true father of wireless.

CHAPTER V

HEINRICH HERTZ, THE FATHER OF WIRELESS

I. THE KIND OF CURRENT WHICH PASSES WHEN A LEYDEN JAR IS DISCHARGED; AND HOW THIS IS LIKE WATER FINDING ITS OWN LEVEL IN A BENT GLASS TUBE. THE IMPORTANCE OF RESISTANCE

I do not suppose that Heinrich Hertz, when he set out to find Clerk Maxwell's electromagnetic waves, had ever heard of Adams and his *Essay on Electricity*. Yet his brilliant mind saw that the secret of wireless waves lay in the very thing that Adams had stumbled on by accident. The secret is to be found in the way that a Leyden Jar discharges.

We have seen that there are two quite different ways in which electrons may move in order to produce a current; they may move in one direction and produce a direct current or they may move first one way, then the opposite way and produce an alternating current. We have also seen that

when this change of direction takes place very rapidly, millions of times a second, the ether round about is not only bent by the lines of electro-magnetic force, it is also made to wobble. The Leyden Jar when it discharges across a spark gap produces oscillations, as these rapidly changing alternating currents are called.

Look at this horseshoe-shaped piece of glass in

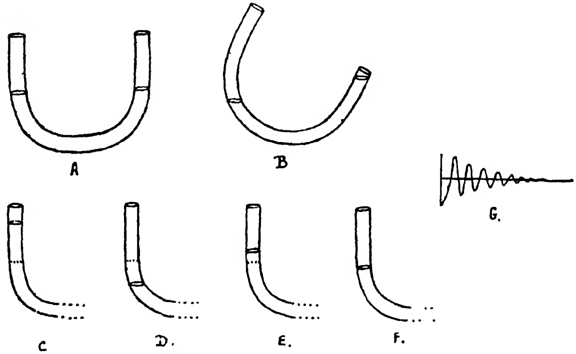


FIG. 25.—Making water oscillate in a glass tube.

Fig. 25. In A you see it resting on a table, with some water in it reaching an equal distance up each side. In B it has been tipped over so that more of the water has gone into the right-hand side. The dotted lines show the original level of the water before it was tipped. Now suppose it is suddenly set straight again. The water will rush back to occupy its first position, but in doing so it will mount up the left-hand side too far as

at C. It will then *oscillate* back again too far below the dotted line as at D; too far in the other direction as in E, and so on, each time missing the right level by less than the previous time until it at last comes to rest as at F. G is a picture or graph of what has been happening, so simple that you will understand it for yourself without any explanation.

Exactly the same sort of thing happens when

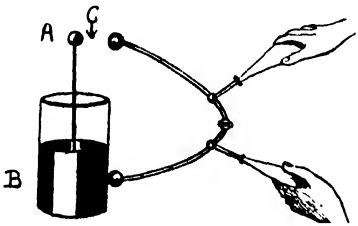


FIG. 26.—Discharging a Leyden Jar across a spark gap.

a Leyden Jar is discharged across a spark gap as in Fig. 26. The knob A has been charged with many free electrons, and so the coating B will have a deficiency of the same number of electrons. You will remember that the lost electrons from B have been pushed away into the earth. With a brass rod we make a spark gap at C; and you can imagine the strain acting across C of electrons and protons aching to be able to join up into balanced atoms.

You remember that we call this the P.D. across

the gap and that the P.D. can be changed into an E.M.F. To do this the gap is made narrower and now the straining electrons at A begin to knock off electrons from the nearest air atoms in the gap and immediately the unbalanced atoms become conductors, the gap becomes a bridge, the electrons rush across to the B side. But, as in the tube of water, they overstep the mark; too many electrons cross over to balance things out, and now the B side is negatively charged with too many electrons and the A side positively charged with too few. At once the electrons start back; once more overdoing it and negatively charging A; and so on until at last the oscillations die down and both sides are balanced. Thus the little graph in Fig. 25 G would do just as well for a picture of the discharge of a Leyden Jar across a spark gap.

But a Leyden Jar or other condenser does not always discharge in this way. If, instead of using a brass ball on the end of a rod as in Fig. 26, we made our spark gap with a piece of damp cloth, the Jar would still discharge, but there would be no oscillations. We can see why very easily if we think back to our tube of water. If the tube had been very narrow, or if it had been choked with sand or blotting-paper, if in fact the *resistance* of the tube had been great, the oscillations would not have looked like the graph G.

They would have been fewer and smaller. The weight of the water falling down the right-hand tube would not only have had to carry the water up the left-hand side, but also to waste some of its energy of motion in overcoming the resistance of the sand or blotting-paper. And so it would not have enough energy over to climb so high above the right level.

Suppose that when the tube had been tipped as in Fig. 25 B you had put a plug of cotton or rubber on the end of a little ramrod into the left-hand side and then after setting the tube straight you had gradually removed it; you would have applied so great a resistance that the water would never rise above the right level, or in other words would not have oscillated at all.

Exactly the same is true with a Leyden Jar. If the resistance of the circuit through which you discharge it is high, the discharging current will not be oscillating, but direct.

II. WHY THE LEYDEN JAR IS A BAD RADIATOR; AND THE CHANGE THAT HERTZ MADE IN ORDER TO TURN IT INTO A GOOD ONE

The Leyden Jar is an oscillator, and therefore the right sort of thing to start electromagnetic waves travelling away from it through the ether; why was it, then, that these waves were not fully discovered by one of the thousands working with

Leyden Jars all over the world since the time of Cuneus and his master ?

You will remember that these waves are started by some of the energy of electromagnetic fields being separated off from the rest when these fields grow and collapse very rapidly. Instead of the energy all going back into the circuit which makes the fields, some of it gets caught up with the ether and *radiates* waves. To be a good wave radiator the circuit must be so made that as large an amount as possible of the energy is used up in radiating. But a circuit the shape of a Leyden Jar does not allow more than a very small part to be so used.

Go back to your bicycle : suppose that besides wanting to get to the end of your journey on the bicycle, you also wanted to use your energy on the way to warm some water, to wash your hands with at the end of the ride. I do not for a moment recommend this plan as being a good practical invention, but it could be done by having a space for water inside the axle, and then the hotter the axle the warmer the water would get. You would prefer then the rusty unoiled bicycle because it would use up more of your energy in producing motion of molecules at the axle and so would warm the water.

The well-oiled bicycle can be compared to a Leyden Jar ; it is so constructed that not enough

energy goes to producing heat for the water, and the Leyden Jar is so constructed that not enough energy goes to radiating electromagnetic waves. How are you to construct an oscillator that does this? That was what Hertz had to decide.

The reason why the Leyden Jar is a bad radiator is easy to see: its plates are close together, so that nearly all the energy of the lines of force is concentrated inside the space between them, and

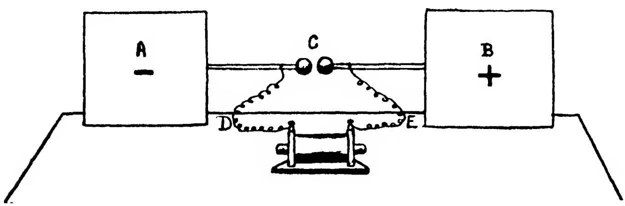


FIG. 27.—This is a picture of the first wireless transmitting station.

very little of it has a chance of escaping outwards through space. So Hertz saw that the first thing to do was to make an oscillator with the plates as far as possible apart. Fig. 27 shows his oscillator.

At first sight it may not look in the least like a Leyden Jar, but you must be careful to see that it is exactly the same as such a jar with the plates as wide apart as possible. Compare Fig. 26 and Fig. 27. The inner plate A is the same as the left-hand plate A in the second picture. The

outer plate B is the right-hand plate B, the spark gaps are both marked C. The wires D and E lead to an electrical machine which makes plate A richer and plate B poorer in electrons, until the P.D. at C is so strong that it breaks down the resistance of the air and a spark passes over.

All this is exactly the same as what happened when we discharged a Leyden Jar, except that this time fewer of the lines of force are actually caught between the two plates of the condenser ; so that, when the time comes, a larger amount of their energy escapes in the form of waves.

The genius of Hertz was the first to see that this would be so, and that is why he was the first to succeed in producing what have ever since been called after him Hertzian waves.

III. OF THE THINGS HAPPENING IN THE ETHER ROUND THE MOVING ELECTRONS, AND ESPECIALLY OF THE FLICKS GIVEN TO THE LINES OF FORCE WHEN THE ELECTRONS OSCILLATE

Hertz set up his oscillator in a large room and began to charge the plates. Think of the invisible parts that we know must have grown out from the apparatus as the electrons began to collect on plate A. All the free electrons gathered here have sent out invisible but energetic lines of electric force. They stretch outward and bend

the ether, and if we were to hang little light balls in their way we should be able to see all the movements and bendings we saw in our early experiments with pens, trousers and the rest.

Presently the spark gap between the rods comes to life. The atoms of air have been waiting in a strained condition; those nearest to the electrons on the brass ball have been buffeted and molested by the electrons in their anxiety to start across the gap. Now one after another these atoms lose their balance and the gap is filled with a bridge of unbalanced atoms or ions. We might call it a suspension bridge this time.

The electrons are under way, the P.D. has become an oscillating E.M.F. All round the electrons a magnetic field has sprung into existence. Let us look at four stages in the life of one of these electrons. Here they are in Fig. 28; in A we see an electron revolving in a well-balanced atom; all its energy goes to keeping itself in its orbit; it does not bother the outside world at all.

In B it is free of any proton and therefore is sending out energy into the world around in the form of lines of electric force. In C it has begun to move, and in circles round it there have come into existence *magnetic* lines of force straining the ether in another way.

A millionth of a second after C, the electrons have changed their direction. We know that this

means that the magnetic field has been completely changed too. To begin with a change of direction means also a coming to a standstill. You

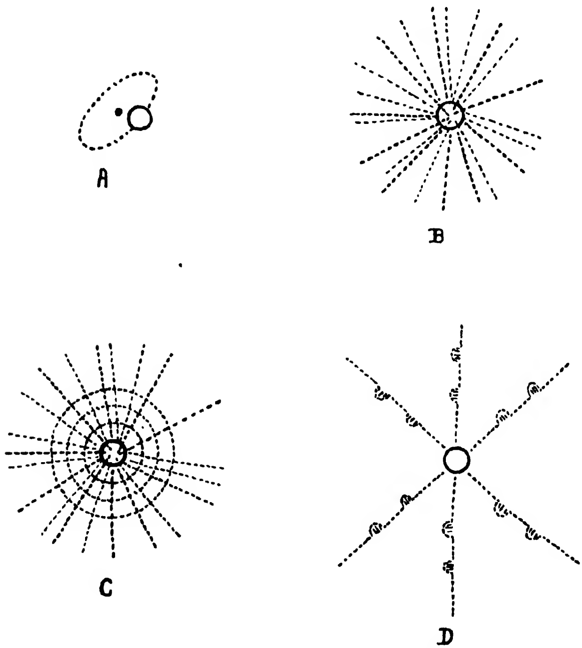


FIG. 28.—Four different stages in the life of an electron. A, An electron revolving in an atom. B, A free electron shooting out lines of force. C, A moving electron with its lines of force electric and magnetic. D, A rapidly oscillating electron splashing the ether.

cannot move from left to right and then from right to left without for a moment walking in neither direction ; and in the same way electrons

moving in an oscillating or an alternating current not only change their direction but their speed all the time ; coming to a complete stop a million times a second if that is the number of times they change direction in a second.

Now every time they stop, the magnetic field collapses altogether, then as they start off again it spreads out in the opposite direction (see Fig. 13). Meanwhile something odd is happening to the lines of electric force. Look at D. The dots are a slice through the magnetic field, just to remind you that it is there ; but look particularly at the loops that have been drawn in each of the electric lines. What do they represent ?

We will take a cord and tie it to a door-handle and hold the other end so that the cord hangs just a little loose. Imagine your hand to be a moving electron and the cord its line of force. Move your hand back and forth slowly from left to right a few inches. The whole cord moves with it. Now increase your speed until your hand is moving very fast indeed ; the cord still has to follow your hand's movement of course, but at the same time you can see a curl or twist travelling along the cord from your hand to the other end. You will recognize the way in which it travels along ; for it is the same kind of motion as we met in the experiment with the ping-pong balls in the bath—a *wave motion.*

I think you will know why the curl comes in the cord, if you remember to think back to this matter, when you read about inertia in the next chapter ; but for the moment all that is necessary is to know that just such a curl comes in the line of electric force when the rapid movement to and fro of its electron flicks it very fast first one way and then the other. The line of force is not really a line or a cord, but a strain or stress in the ether, and of course it is not tied to a door-handle or anything else, but it works the same way as our simple illustration.

We must imagine what we have seen happening to one line happening to billions of lines at once and in all directions and then you will see that the flick or curl of all the lines together is like an expanding ball growing out in all directions ; and this expanding electric field carries with it an expanding magnetic field as well, indicated by the dots in Fig. 28 D.

If you bear in mind all this complicated invisible part of Hertz's oscillator, you will see that what he did by opening out the distance between the plates to the greatest distance was to see that as much as possible of these outward expanding flicks got away without being held back by the powerful electric field between the plates. And he was so successful that he was able not only to send out these waves, but to know that he had

done so in the only way possible, by catching them again in a detector.

Before looking at the detector, we will glance back at all the steps that led up to the coming of this first real wireless transmitter.

IV. A BACKWARD GLANCE OVER THE HISTORY OF CONDENSERS UP TO HERTZ

Here are some of the steps that led up to Hertz and his successful radiation of wireless waves:

1. For millions of years nature had been developing an apparatus, which we call the eye, for detecting ether waves coming from natural radiators in the sun and stars.

These radiators were atoms in which electrons were jumped from one orbit to another.

Atoms are tuned to send out ether waves of between 400 and 800 billion to the second. So nature's receiving set, the eye, is tuned to receive these wave frequencies and no others.

2. In 1727, at Leyden, Cuneus and his master, working on wrong theories about electricity, hit on the condenser, named after their city the Leyden Jar.

3. In 1780 Adams accidentally noticed that sparks could be collected from near-by conductors, although they were not attached to the Leyden Jar, whenever a Leyden Jar was made to discharge over a spark gap.

4. In 1860–1 several scientists showed that the discharge of a Leyden Jar was oscillatory.

5. In 1864 Clerk Maxwell showed by mathematical reasoning, not only that light was electromagnetic waves, but that other invisible electromagnetic waves must exist, or could be made to exist.

6. In 1877 Elihu Thomson saw sparks kindled by ether waves when he was busy with quite another experiment. Nothing came of the accident, which probably happened to many others at this time.

7. In 1879–80 Hughes accidentally hit upon ether waves, but his attempt to prove their existence was looked down on by the bigwigs. He was so discouraged that he did not go on with his experiments.

8. In 1883 a scientist named Fitzgerald proved that Leyden Jars *ought* to produce " Maxwellian Radiations ".

9. In 1887–9 Heinrich Hertz by turning a " closed condenser " like a Leyden Jar into an " open condenser " with the plates wide apart was able actually to produce ether waves of a different length from light waves.

But of course that is only half Hertz's story. He also produced a detector, the first artificial electric eye, the first wireless set, with which he caught the waves he had himself sent out.

V. THE APPARATUS WITH WHICH HERTZ CAPTURED HIS ETHER WAVES AND PROVED THAT THEY REALLY EXISTED: AND HOW HE SHOWED THAT THESE WAVES BEHAVED IN EXACTLY THE SAME WAY AS LIGHT

I think you will agree that the Hertzian Oscillator, the first wireless transmitting station, was very simple. The first receiving set was even

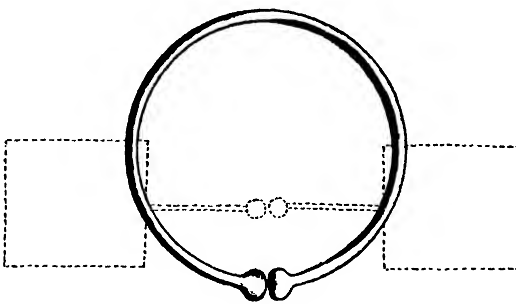


FIG. 29.—The first of all wireless receiving sets, with the first wireless transmission set sketched in in the background.

simpler. Look at Fig. 29, where you will see the father of all wireless receiving sets, a simple metal ring with two knobs not quite touching.

He called it his Resonator because it was going to resound to the oscillations sent out by the Oscillator. Hertz set up his Oscillator at one end of the room and his Resonator at the other. Next he turned on his electrical machine and charged the two plates of the Oscillator. Presently

a spark leaps across its spark gap agitating the ether round about; waves of electromagnetic force sweep outwards through the room, through the walls, the ceiling, the floors.

The lines of magnetic force surge outwards and cut across the metal loop or Resonator. Now we have seen what happens when a magnet is brought near a conductor; the free electrons in the conductor move. Look again at Fig. 10, and imagine instead of a solid magnet being brought near the wire a train of magnetic waves; then you have a picture of what is happening to the Resonator. One after another the magnetic lines cut through the circle of copper and as they do so the electrons in the circle move. Immediately after, perhaps one-hundred-millionth of a second after, the current changed direction in the Oscillator, coming to a complete stop for a moment on the way. When this happens the lines of magnetic force are sucked back into the Oscillator again and once more on their return journey they cut across the Resonator and start the electrons moving in the opposite direction; and so on, as long as the Oscillator continues to send out and suck in again an alternately growing and collapsing field of magnetic waves.

Now suppose the Resonator is fixed in a position so that the metal hoop on one side of the gap is nearer the Oscillator than the hoop on the

other side; then the two sides of the gap will be cut across at different moments and a current will be started round the circuit. This current will be an oscillating current exactly like the one that originally started it in the Oscillator, and it will jump back and forth over the gap in the same way. In short, the presence of the invisible magnetic waves will be proved by a spark in the Resonator.

With infinite patience Hertz made his Oscillator oscillate and moved his Resonator from place to place in search of the invisible and unknown. How different it was for him from our task of turning the dials to find some distant station. He was searching for something that no one had ever found. All he had to go on was faith that Clerk Maxwell's mathematics was right, and faith that his own experimental genius was using suitable apparatus.

Suppose Hertz had a housekeeper or a charwoman who had to keep her master's rooms tidy; can you imagine how unsympathetic she would be with all this business? Suppose, after days of experimenting, at last a tiny little spark appeared between two balls of a metal loop, and suppose that in his excitement Hertz had told the charwoman to come and see; how little would she have been impressed. An almost invisible spark a few feet away from another spark, that was all;

and yet it meant one of the greatest scientific triumphs since Newton watched, or did not watch, an apple fall to the ground and thought out the laws of Gravitation as a result.

And we should remember that to Hertz this triumph was not, as it is to us, the *beginning* of wireless, that practical blessing, used in a thousand ways to-day to help, amuse, teach, the human race. It was the *end* of a search for truth. Hertz never once thought that what he was doing had any practical or commercial value. It was enough for him that he had proved that a great mathematician was right, that he had succeeded in revealing how nature worked.

Hertz went on to conduct a whole series of brilliant experiments to show that not only did these invisible waves exist, but that they behaved in exactly the same way as light. He constructed simple rough apparatus to show that he could reflect them just as light waves are reflected in a mirror, that he could split them up, as light waves are split up in the rainbow, or in a prism ; that he could refract them and do all the other things that can be done with light.

And so Hertz created the first electric eye. We may say that his electric eye was in very much the same state of development as the worm's eye, and we must now trace the steps by which this first worm's electric eye gradually developed into

the complicated, wonderfully sensitive electric eye, our modern wireless receiving set; the brown box which, as I said in the beginning, we are too apt to take for granted, because we can buy it at a shop and turn it on or off as we like without thought or knowledge of the great story of its coming to existence.

CHAPTER VI

A PLUNGE INTO DEEP WATER

I. SIR OLIVER LODGE'S SYNTONIC JARS AND A FIRST GLANCE AT "TUNING IN"

THE really important change that Hertz made was to put the plates of his Oscillator as far apart as possible, so that a large part of the energy from the current could escape and radiate outwards in waves. In this way his wireless signals were stronger than the chance ones that escaped from Leyden Jars. But his worm's eye of a detector was a very poor affair.

At almost the same time as his great experiments, another scientist was showing how to make an electric eye able to detect a greater amount of the signal originally sent out. Sir Oliver Lodge made a very simple discovery which you could repeat in any physics laboratory; but for all its simplicity it was to have a very great effect on the coming of practical wireless.

In Fig. 30 you see two Leyden Jars standing

near one another on a table. They are not touching one another in any way; their wires and spark gaps are arranged parallel and that is all.

The farther jar has been attached to an electrical machine to charge it; so that when the experimenter wishes, a spark will jump across the gap between the two balls. The nearer jar is

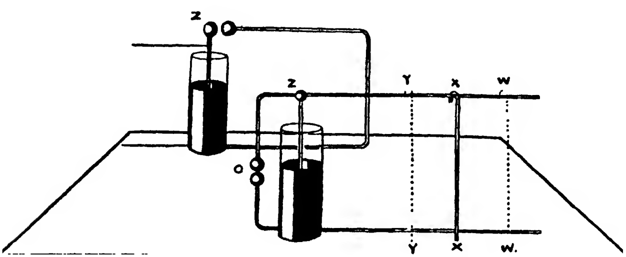


FIG. 30.—Sir Oliver Lodge's Syntonic Jars which used the idea of resonance. The line XX is the earliest form of what you probably call the "tuning dial" of your set.

exactly the same size as the other but instead of the spark gap being at the top it is arranged near the side. You will see how the circuit goes, if you look at the sketch and remember that the balls marked Z in each jar are connected to the inner metal lining below.

You will notice that at XX, there is joined a sliding wire, which can be moved nearer the jar or farther away, let us say to YY or WW.

Now what Sir Oliver Lodge found was that when a spark passed between the balls of the first Leyden Jar, another spark passed between the balls of the second jar, although there was no connection at all between them. *BUT* this only happened when the sliding wire was at XX and *never* if it was at YY or WW. Why was this ?

Every time you use your wireless receiver you do exactly the same as Sir Oliver Lodge was doing when he pushed the moving wire up and down to find the place XX so that his Leyden Jar would spark. You turn little dials to *tune in* the right wave length and that was what he was doing—when he moved the wire up and down—*tuning in.* He was making the length of the circuit in the second jar such that it was in tune to receive the wireless influences from the other jar.

This picture of Lodge's Syntonic Jars shows you how it was first learned that in order to detect signals sent out by an oscillating discharge the detector must be tuned to be in resonance with the Oscillator or Transmitting Station. Now what do we mean by the phrase *in tune* ?

II. A DANGEROUS BATH EXPERIMENT AND A GUIDE TO HOW TO SWING A SWING. WHY SOLDIERS BREAK STEP CROSSING A BRIDGE. HOW THE DIFFERENCE BETWEEN AIR WAVES BEATING 264 TIMES A SECOND AND AIR WAVES BEATING 260 TIMES A SECOND MAY MEAN THE DIFFERENCE BETWEEN GREAT JOY AND TEMPORARY INSANITY. WHY THE FURNITURE SOMETIMES SINGS

Go back to your bath for a moment and conduct a really dangerous experiment. Fill the bath very full and lie in it. Then very gently arch your back and relax alternately until the water begins to produce a high tide at one end and a low tide at the other end of the bath.

If you are careful to make your movements *in tune* with the movements you set up in the water, you will soon be able to deposit nearly all the water on the floor. Now if you had tried to lift that weight of water out of the bath, or to push it out in some way or other, you would have had to use a tremendous amount of energy; but by tuning your movements correctly you have moved the water with very little effort indeed.

You will notice that the water, once you start it off, moves in a special time of its own. If you had three baths in your house, each of a different length and breadth, you would find that you would

have to alter the timing of your movements in all three cases so as to be in tune with the water. If you have not got three baths, you will be able to see the same thing by filling the level of the bath to a different height. Each volume of water has a different natural pace at which it keeps swinging, once you give it a start, and to shift the water with least effort you must tune your own swinging to the natural swinging time of the particular volume of water you are using.

If you are careful you can make your experiment less dangerous, and far less unpopular with the rest of the household, by suddenly altering your timing, when the tide has got sufficiently high. You will then act as a brake on the movement of the water and quickly reduce it to a peaceful level again. In other words, not only can you tune in to the right wave length of your bath water, you can also tune out.

Or again, think of what happens when you swing a swing. Once the swing is moving, it is surprising how little effort you have to put into swinging to make it move higher and higher. But this effort must be in tune with the swing. Push just a little too soon and you are as likely as not to hurt your wrist. Push a little too late and instead of helping the swing you will find yourself running a few steps forward after it.

Once more we find that to use energy to the

full and to waste as little of it as possible, we have to use it *in tune* with the movement of the thing we want to influence.

There is another very interesting example which everybody knows. When an army is crossing a bridge the soldiers are always made to break step. Why?

Because an army marching in step is producing a rhythmical movement; we even talk of them swinging along. The bridge, however strongly built, will be made to swing on its foundations. The first men may move it a millionth of an inch back and forth, but this millionth of an inch is like the first touch given to a swing. If it happens that the rhythm of the march is in tune with the natural rhythm of the bridge, the bridge will be made to sway more and more until it may even break, *not* because of the *weight* of the men crossing but because of their *rhythm*.

Why do we call this very important fact being *in tune*? Because by far the simplest and best-known example of it comes from music.

If you strike the note called Middle C on the piano, you are making an air splash from which there go out in all directions air waves of such a length that two hundred and sixty-four pass a given point every second. When your ear gets in the way of these ear waves it sends a message to your brain, which you interpret as: "there

goes Middle C". Your ear is able to register air waves of any frequency from rather less than sixteen a second up to a good deal more than fifteen thousand.

If when you hear this note started by the piano's air-splashing, you sing the same note, what exactly do you do in terms of air waves? You use your throat muscles to start your larynx vibrating two hundred and sixty-four times a second; and your larynx, beating on a column of air in your throat, starts the air beating at two hundred and sixty-four times a second as well; and the result is Middle C in unison with the piano. But suppose your muscles and nerves are not sufficiently trained to work with perfect accuracy. As a result your larynx starts the air vibrating at only two hundred and sixty times a second; then you will be *out of tune*. You will make sensitive people shudder. It is a very strange thing, well worth thinking about, that the difference for some people between sublime pleasure and considerable pain may be nothing but a difference of, say, four in over two hundred beatings of air molecules in a second.

The human brain is made in such a way that although it loves to hear several people singing —that is, splashing the air—a note with a frequency of two hundred and sixty-four, it will suffer from temporary insanity if it has to hear

one person producing air disturbances of two hundred and sixty-four, another disturbances of two hundred and sixty, and a third disturbances of two hundred and sixty-eight, all at once. It is a very curious thing.

Here is another thing just as curious. Everything in the universe, whether it is a musical instrument or not, has a favourite note, which it will sing, if it can, whenever it hears it sung by anything else.

You must have noticed how, when a piano is being played in a room, every now and then a hanging lamp, or a picture frame, or an ornament will sing out the same note as the piano. This is because what is called the natural resonance of the object is the same as the piano note. As I have said, everything has a natural resonance but most things are stopped from singing by the things round about them, or by the way their molecules are packed together. The lamp, or the frame or the ornament happen to be so placed that nothing stops them when they begin to vibrate, and so when the air brings them the special note which is their natural note they can respond.

We will be able to see this very clearly if we take the case of two violins lying near one another. You know that violin strings vary in thickness. The one that produces the note E is very thin

and the one that produces the lower note G is thicker. Also if a player shortens the string with his finger we know that the note changes to a higher one. In short, the note coming from a violin string varies according to the length and thickness of the string. By putting his finger on the proper place on the G string, the player can sound E. In fact a short-thick and a long-thin string have the same natural resonance and will produce the same note when played. Remember carefully that the resonance depends on two things, length and thickness, and that we can get the note we want by varying either or both. We shall meet something very like this in wireless.

Suppose now that we have two violins near one another and that someone plays E on one of them. They are making a string vibrate in such a way that the air around also vibrates the right number of times a second to produce the note E. If you put your ear to the E string of the other violin and listen very carefully, you will hear that it too is sounding out the note E. If now you put your finger on this string and shorten it just as a violinist does, it is immediately silent.

If you put your finger on the G string and shorten it to the length which produces the note E when it is played, you will now hear this string singing the note softly to itself.

You will see that the two violins are really a

wireless air-wave transmitter and a wireless air-wave receiver and that the receiver will only be able to receive provided it is tuned to exactly the same wave length as that sent out by the transmitting violin. Directly you change its shape you change its resonance and the receiver is silent.

Now this is exactly what happens with ether waves and the circuits that transmit and receive them. Every electric circuit has a natural resonance, a definite wave length that it can transmit or receive. To send out an ether wave of a given frequency you must have a transmitter tuned to that frequency, and to detect the ether wave at the other end you must have a detector or receiver tuned to the same resonance.

Now look at Sir Oliver Lodge's Syntonic Jars again : the moving wire XX obviously lengthens or shortens the circuit of the " receiving " jar by cutting out or adding a certain amount of copper wire. The current that passes through the circuit OXX passes through more wire than if it passed through OYY. And it is this that settles the question whether the jar will spark or not. If XX is in the right position to make the resonance of the circuit the same as the resonance of the other circuit, then it will pick up the ether vibrations and spark.

We have seen that Lodge's Syntonic Jars did not lead to wireless because a condenser with its

plates close together does not radiate properly; but they are of the greatest importance because they showed the necessity of tuning—the principle of syntony as it is called. It was when syntony was added to Hertz's open condensers that things really got started.

Now the violin strings were "syntonic" when their thickness and length were right. What properties of an electric circuit correspond to the thickness and length of a violin string? What do we have to alter and match in our circuits so as to make the transmitting circuit and the receiving circuit in tune with one another?

III. INTRODUCING INDUCTANCE, INERTIA, KINETIC ENERGY BY WAY OF A TRUCK MOVING ALONG A SMOOTH RAILWAY LINE. THE LAZINESS OF ALL THINGS WHICH MAKES THEM WANT TO BE LEFT ALONE AS THEY ARE

We can tune a violin string in two different ways. We can alter its length or its thickness. In practice it is of course much easier to alter its length than its thickness; and so we have a few strings of different thicknesses side by side and do the rest of the tuning by changing their length with our fingers.

In the same way there are two things about an electric circuit that can be varied so as to give

the circuit a required resonance. I am going to make an exception to my usual rule this time and tell you the names of these two things before we find out what the names mean. The two variable things in a circuit which are used to tune the circuit to the required resonance are its inductance and its capacity.

Just as two strings may be in resonance with one another although their lengths are different, provided their thicknesses are right, so we are going to find that two circuits will be resonant to one another even if their inductances and capacities are not the same, provided the inductances and capacities taken together have the right value. As this is the fundamental truth about resonance in wireless, let us express it as clearly as possible. Suppose the inductance of the first or transmitting circuit is L_1 and its capacity is C_1; and suppose the inductance of the second or receiving circuit is L_2 and its capacity C_2; then it does not matter at all what these four letters L_1 and L_2, C_1 and C_2 stand for, *provided* L_1 multiplied by C_1 equals L_2 multiplied by C_2. Or put more shortly, we say that :—

Two circuits are syntonic when their LC value is the same, and since tuning is nine-tenths of wireless you will see that we must know exactly what this means.

First of all, what is the inductance of a circuit ?

Let us begin by thinking of something like it which we can see. Suppose you have a good straight piece of railway track and a railway truck on it, moving slowly along. It does not cost much energy to keep the truck moving, especially if it is well greased and cared for. You have probably often seen a railway porter pushing a heavy truck in this way.

Now, what is the work that has to be done to keep this truck moving? When they first ask themselves this question most people answer that the work has something to do with pushing a weight. They are wrong. The weight of the truck makes it want to fall towards the centre of the earth, and it is prevented from doing this by the ground underneath it. So the weight of the truck is taken care of by an equal push upwards from the ground.

The truth is that the moving truck would like to go on moving for ever in exactly the same way as it is going, and the only thing that prevents it is that this " energy of motion ", or kinetic energy, is gradually wasted and spent in overcoming the friction at the axles and elsewhere in the wheels. Because the moving truck has to waste some of its energy in making the molecules in its wheels dance faster, it gradually has less and less energy left for going on moving and at last comes to a standstill.

All the porter has to do is to overcome this waste

of energy, to make good with his own energy the part of the truck's energy wasted in overcoming friction and producing heat.

But now suppose the porter tries to make the truck go faster or to stop it from moving at its own pace ; now, indeed, he has a hard task ; for he has to overcome a new force altogether which is called *inertia*. We must learn what inertia is and why it is called that.

You have often heard of people suffering from inertia or laziness. They show their inertia by always wanting to be left in whatever position they may happen to be in. You could not have a better description of what is meant by the inertia of a railway truck, or any other body, than this. Inertia is the characteristic which makes anything want to remain exactly as it is and resist any attempt to alter its present condition. If anything in the universe is standing still, its inertia resists any attempt to make it move. If anything is moving, its inertia resists any attempt to make it move faster, or slower, or stop altogether.

To keep the truck moving at the same pace, all you have to do is to make good the energy wasted in friction and heat ; but to start it from rest, to stop it once it is started, or to alter its pace to faster or slower, all these require you to use your own energy to overcome its inertia.

Now when electrons are moving in a circuit, they too have inertia. To start them in the first place this inertia has to be overcome and to stop them again it has to be overcome once more. What is this thing responsible for the inertia of moving electrons, which resists all changes in their rate of moving? It is *called* inductance. But what *is* it?

IV. WHAT THE WORDS INDUCTION AND INDUCTANCE MEAN. THE WAY IN WHICH CURRENTS CAN BE PASSED FROM ONE CIRCUIT TO ANOTHER. WITH A WARNING AGAINST BEING FRIGHTENED BY BIG WORDS

Whenever you meet with a scientific word, like inductance, try to think of words like it that are used in ordinary everyday speech; and try to think out why the first scientist to use it, chose it out of the common speech for his scientific purpose. Long years of muddle and haziness about a theory or a scientific fact can be saved by looking words fair and square in the face at the very beginning.

People often feel sure that a scientific idea must be difficult because they are afraid of the word used to describe it. We are most of us great respecters of words. We are even willing to pay heavily for their use, provided they sound pompous enough. For example, if your nose has to be

blown more *often than is convenient, you call in Dr. Quack. He looks at you solemnly and shakes his head.* "You have got an *attack of rhinitis,*" he says.

"*Oh dear,*" *you reply,* "*I had hoped it* was *only a common cold.*"

"Not at all, I'm afraid; a clear case of rhinitis." Now rhinitis comes from two Greek words meaning a snout—hence also rhinoceros—and inflammation; and it is only a pompous way of saying you have inflammation of the snout, or in good English, "a code id de dose". But Dr. Quack knows that rhinitis will mean more medicine and a bigger bill.

In the same way inductance and induction, two scientific words used in electromagnetism meaning the same thing, may sound difficult and yet I know I can *induce* you to see how easy they are to understand. If I *induce* you to see this, I shall have *induced* the same idea in your mind as already exists in mine. We shall have put our heads together and a current of thought will be *induced* in your head by the current of thought in my head.

Aha! Now you know what induction is, don't you? When I move a magnet towards a coil of copper wire, a current is *induced* in the wire by the magnetic lines cutting the coils. Another example of *induction* is to be seen in

Fig. 31, which shows apparatus used by Faraday a little more than a hundred years ago to *prove* that, when a circuit through *which a current is* moving is moved nearer or farther away from a similar circuit, a current is induced in the second circuit.

P is a coil of wire joined to a cell, like the one we saw in the bell-circuit; and K is a key for letting down a drawbridge so as to complete the

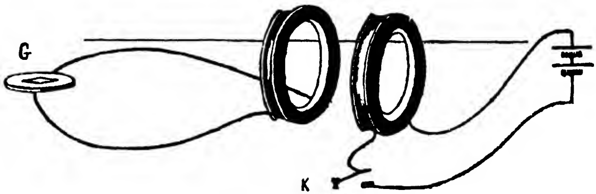


FIG. 31.—Faraday showed how to make electrons move in another circuit with apparatus like this.

electron road, exactly as we did with the bell-push at the front door. S is another coil of wire fitted to G, an instrument for recording the flow of electrons in the circuit.

There are four ways of making an induced current pass through the circuit SG: you can press down the drawbridge to complete the other circuit, and then in the brief moment during which the current is beginning in the PK circuit, G will register that electrons are moving in the

other circuit as well. The same thing happens when you take away the drawbridge so that the current stops in the PK circuit. During this moment there is another induced current in the SG circuit, or the secondary circuit, as it is sometimes called.

The other two ways are to keep the current steadily moving in the PK or primary circuit and then to move P nearer or farther away from S. So long as P is moving, there will be an induced current in SG. You know the reason for all these induced currents, they are not new to us. They are caused by the fact that the number of magnetic lines of force cutting across the secondary circuit is being made to vary. It is important to distinguish carefully between all these currents induced in one circuit by a neighbouring current and the currents produced by Hertz's ether waves. An induced current is due to the lines of force themselves, while the current formed in a receiver is due to the vibrating of the ether when these lines of force grow and collapse very fast indeed. The induced current is formed by the energy pushed out and sucked back by the primary current; but the other is formed by the lost energy that never returns, because it is spent in vibrating the ether into waves.

It is interesting to know that when Hughes asked the bigwigs to call and see his experiments,

they insisted that what they were shown was nothing but the result of induction, and therefore nothing new. " Of course there is nothing new in all this," they said. " The secondary current is due to induction from the primary current; and we know all about that already." So Hughes never became the discoverer of wireless. Of course the bigwigs were wrong, as you and I know, but if you think of it, it was not a very

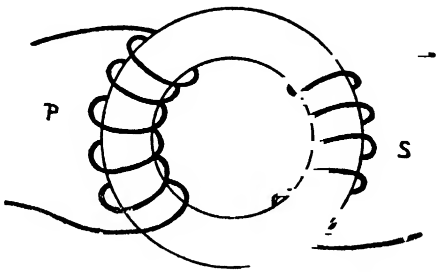


FIG. 32.—Faraday's ring. A current in the wire P starts electrons moving in S.

surprising mistake. Induction is a strange fact and it is always tempting to bigwigs to explain a young experimenter's discoveries by something everybody knows.

A most valuable use of inductance—or induction, there is no difference between the two words—was invented by Faraday. Fig. 32 shows " Faraday's ring ", an iron ring with a coil P and a coil S. The letter P is used of course for primary, and the primary coil is the one in which

a current is made to flow first. S is the secondary coil, in which a secondary current is induced by the primary current.

This ring is the first stage in the development of the very powerful electrical machine called an Induction Coil. When an electron flow takes place in the primary coil it not only cuts across the secondary coil with its lines of force, but it magnetizes the iron ring, and the magnetic field

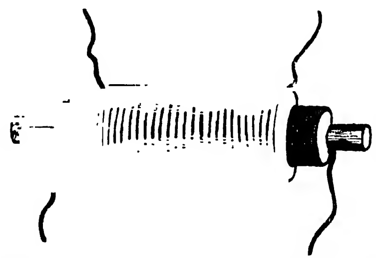


FIG. 33.—Another step towards the modern induction coil.

of the ring increases the induction effect and a stronger current is induced in the secondary coil, than would be induced with the iron ring.

The next step towards a modern induction coil was the winding of both coils round and round the same bar, one outside the other, as in Fig. 33. There is a most important rule about the pressure of electricity in such a coil. If you use a very much thinner wire for the secondary coil, so that it has a great many more twists to it than the primary, your induced current will be much

stronger than the primary current; and this is called stepping up the pressure of the current. On the other hand, if you want to step down the pressure of the current you use thicker wire and fewer twists in the secondary coil.

Think how useful induction is. You can transfer a current from one circuit to another and in so doing you can transform it into a more powerful or a less powerful current. You can, for example, catch a current from somewhere in one circuit, and then pass it on to another circuit in a changed form suitable for working a piece of machinery which would not have worked so well with the current you first caught.

But there is one thing you must remember constantly: it is only when the current is changing, that is when the rate at which the electrons are moving varies, that induction takes place. A steady current does not induce a current in another circuit except when it starts and stops; at "make" and "break" as it is called. And so in the induction coil, there is always a device to make and break the current in the primary coil very rapidly. Then at every make and break an induced current takes place in the secondary coil. If there are a great many twists in this secondary coil you can step up the pressure of the current until it is able to produce very long sparks indeed.

V. SELF-INDUCTANCE AND HOW IT ACTS ON THE CURRENT IN THE SAME WAY AS INERTIA WORKS ON THE RAILWAY TRUCK. A BACKWARD GLANCE AT ALL THE MOVEMENTS GOING ON IN A COPPER WIRE

We know that moving electrons are surrounded by electromagnetic fields, and that whenever their speed or direction changes these fields change too. We also know that any conductor cut across by a changing number of lines of force has a current induced in it. Look at those words, *any conductor*. When someone says, " everybody in the room please shut their eyes ", there is usually one person in the room who does not shut his eyes, namely, the speaker himself. And so with the words " any conductor ". Thinking of them you have probably forgotten the primary conductor itself. The lines of force from electrons moving in a conductor spread out in all directions and on all sides of the electrons, and so some of them must cut across the very selfsame conductor in which the electrons are moving. And as the lines of force change in number, they set up a secondary movement of electrons distinct from the primary movement, but in the same conductor. This is called *self-inductance*.

Imagine a single coil of wire through which a current passes. All round the moving electrons

is an electromagnetic field. It grows and collapses whenever the current changes, and as it does so a varying number of lines cut across each twist from the electrons moving in the other twists.

Now there is a very important rule about these secondary currents due to inductance. When the current is starting up and the electromagnetic fields are expanding outwards away from the moving electrons, the secondary current would like to be in the opposite direction to the main primary current. So that as this main movement of electrons is gathering force it meets with an opposition pressure in the opposite direction; the effect of this is to slow up the rate at which the main current gathers speed; to hold it back in other words. Then when the fields are being sucked back into the electrons again, the induced secondary current is in the same direction as the flow of the main current; so that just at the moment that the speed is dying down there comes along an extra induced current to give it a little push and prevent it from dying down as soon as it would ordinarily.

And so the self-inductance of a circuit acts in exactly the same way as the inertia of the railway truck; it tends to put a break on any change; it makes a current which is being born be born slower and a current which is dying die more slowly.

Now we have seen that with an ordinary direct current induction only takes place at " make " and at " break ". It is very different with an alternating current. Here the rate of change varies all the time and so induction goes on all the time.

Let us pause and take a breath and consider the complicated state of affairs going on inside a copper wire through which an alternating current is passing:

1. The molecules are keeping up a perpetual dance, hitting into one another billions of times a second. If they dance faster we say that the wire is getting hotter; for heat is nothing but motion of molecules.

2. Inside the copper atoms electrons are rushing round their paths held in place by the attraction of the protons in the nucleus. One electron path leads its electron far away from the nucleus and thus makes the bond holding it within the atom weak and liable to be destroyed.

3. Among these atoms are wandering a large number of free electrons not attached for the moment to any atom. Their movements are haphazard and in all directions and millions of times a second they step into an atom by taking the place of another electron which has been banged out of its wandering path, either into freedom or into another neighbouring atom.

4. At a suitable point in the circuit we artificially pile up a surplus number of free electrons, and by doing this we change the haphazard movements of the free electrons into a determined movement in one direction aiming at an even distribution of free electrons all round the circuit.

5. A hundred-millionth of a second afterwards we artificially create a scarcity of free electrons at the same point as previously had a surplus and at once the movement of electrons round the circuit is reversed in an effort to restore even distribution once more.

6. Some of these moving free electrons are stopped by atoms and molecules getting in their way. They pay the offending obstacle out by sending it spinning faster than it had been spinning before, and this explains the heat due to resistance in the wire.

7. Round all these moving electrons there appear fields of electromagnetic force growing and collapsing as the current changes.

8. As these lines of force grow and collapse they cut across parts of the copper wire and by so doing set up a new pressure of electrons pushing sometimes with and sometimes against the main stream, but always in a way that tends to slow up all changes in the speed of the electrons.

Of course the shape of the circuit has a great deal to do with the amount of self-inductance

that there will be in the circuit. Even in a perfectly straight wire a certain amount of self-inductance will exist because a few of the lines of force will cut across the wire itself. But, as we have seen, if the copper wire is twisted into a coil, far more lines will cut across the circuit and there will be far more self-inductance.

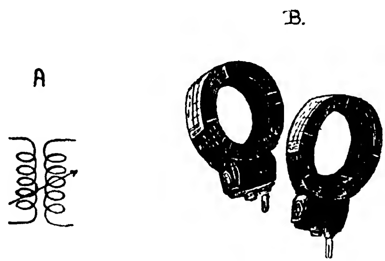


FIG. 34.—A is the sign for B which is two coils coupled to produce inductance.

As we shall see later, we often need to increase the self-inductance of a circuit. We already know that the resonance of the circuit depends on the LC value of the circuit, and of course one way of increasing the LC value to the right amount is to increase the value of L or inductance. To do this we put into the circuit a coil of wire which has a certain measured amount of inductance.

Often, usually in fact, it is not enough for our purposes to put in an inductance of a certain *fixed* value. We want to vary the inductance

from time to time as we tune in one wave or another ; and so we use a *variable* inductance, like those shown in Fig. 34 ; the electrical draughtsman uses the sign at Fig. 34, A, to show a variable inductance in a circuit.

The only difference between a fixed and a variable inductance is that the latter has a moving slide, or some other means of increasing or decreasing the amount of inductance you add to the circuit without your having to add or to remove any thing from the circuit once it has been made.

VI. A MAD INVENTION TO ILLUSTRATE INDUCTANCE AND CAPACITY, BEING THE STORY OF HOW A FOREMAN WAS OUTWITTED AND A GAME OF CHESS CONTINUED IN SPITE OF A WEIGHT AND BY MEANS OF A SPRING

We have so far met with two things that complicate the movement of electrons in a piece of copper wire. First there was resistance caused by molecules getting in the way and producing heat as a result of the inevitable collisions. Next there was inductance caused by a rival flow of electrons in a direction which always slows up changes. We have still to deal with Capacity.

But first let us invent a mad invention that could never exist in the everyday world. Let us suppose that we are in a factory full of huge

machines. Among other things there are two great pistons side by side and moving backwards and forwards with an equal stroke. On top of each there is a seat so that a man can sit and move with the piston to oil it when necessary. Your best friend is the oiler on one piston and you are the oiler on the other.

Back and forth you both go, side by side hour after hour. The piston strokes never alter. You get used to the motion and spend your time talking to one another ; you go further, you balance a chess-board between you and get deep into a complicated game. The foreman comes along and watches you. He sees at once that, thanks to the chess, you have forgotten to oil the machine. What does he do ? Being kind-hearted he does not give you the sack ; he resolves to separate you.

He has a heavy weight tied to the lower side of your piston. Now what happens ? When the piston carrying you forward gets to the end of its stroke, the inertia of the weight wants to go on in the same direction ; it therefore resists the return of the piston in the other direction. The other piston carrying your friend, gets ahead, the strokes no longer move evenly together, the chess-board is sent flying and there is nothing left for you to do but oil the machinery (Fig. 36).

Now this is exactly what inductance does in electricity. Supposing you have an Oscillator or

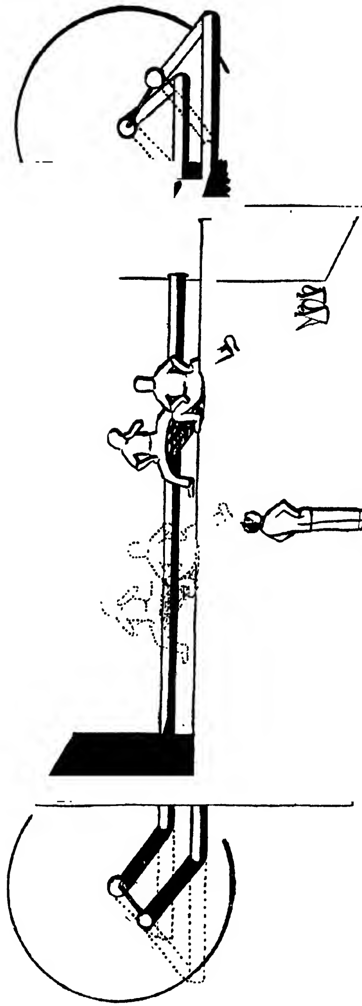


Fig. 35.—A mad invention, Part 1. The men have to sit all day on the piston rods so as to oil them. As they move up and down always opposite one another they forget work and play chess. What does the foreman do?

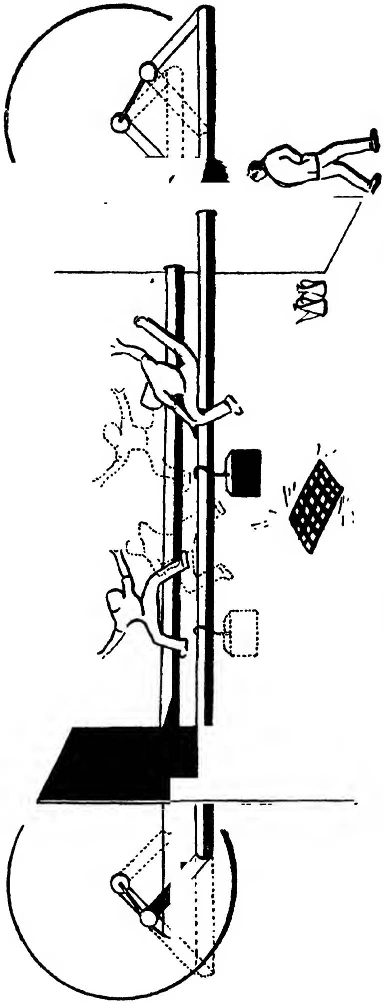


FIG. 36.—A mad invention, Part 2. The foreman ties a weight to one piston and this is what happens. This illustrates inductance. But the men have a trick to play too.

Transmitting Station sending out wireless waves of a certain frequency ; we know that the Receiving Circuit will only register the signals if it is tuned properly. If there were no inductance in the circuit all might be well, but the inductance, by slowing down the rate at which the oscillations change from one direction to the other, gets the current in the circuit out of step with the wave that started it and so the ability to detect the signal is weakened ; the circuit is not in resonance with the ether wave and trouble overtakes you.

Now suppose you and your friend in the dream factory decide that you must finish that game of chess and suppose there is no way of getting rid of that weight ; what can you do ? You are very clever people and so you get a spring and tie one end to the weight and the other to the wall in front of the piston end (Fig. 37). Now when the piston approaches the end of its forward stroke it compresses the spring ; so that even before the piston changes its direction the pressure in the spring is pushing it back ; and when the piston gets to the other end of its stroke the spring has been pulled out beyond its proper length and once more it is urging the piston to return quicker than it ordinarily would. Now you have got the inertia of the weight slowing up the natural changes of the piston stroke and the springiness of the spring hurrying them on. By careful adjustments you

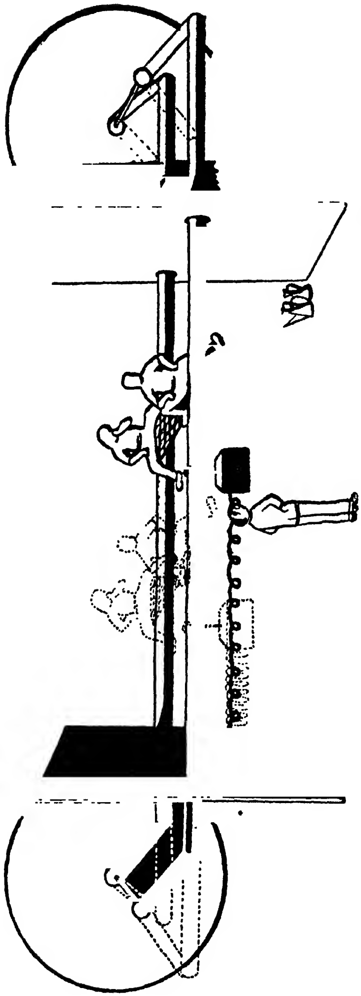


FIG. 37.—A mad invention, Part 3. They tie a spring to the weight and to the wall. Once more they can play chess. They have balanced the effect of inductance with capacity.

balance the inertia of the weight against the springiness of the spring, and when the foreman comes back, he finds the two pistons moving side by side and you playing chess. What happens next does not concern us.

Now just as the inertia of the weight is a mechanical counterpart of the inductance of a circuit, so the springiness of the spring is a mechanical counterpart of the *capacity* of a circuit.

Capacity, whatever it is, acts to counteract the effect of inductance ; and by balancing it against the inductance we manage to keep the current in our receiver in step with the wireless wave and therefore in step with the current in the transmitting circuit.

Now what can it be in a circuit that is called Capacity and acts to speed up the changes in electron flow ? We have already met it on page 114, when we were considering the action of a condenser. We will look at it from another angle so as to see how the action of a condenser can possibly behave in the way a spring behaved in our phantom invention.

VII. HOW WE CAN INCREASE THE CAPACITY OF A CONDUCTOR OF ELECTRICITY

Think of two milk bottles, one holds a pint and the other holds a quart. Suppose we put exactly the same amount of milk into each : one is now

full and the other half empty. Nothing could be simpler.

Next let us imagine ourselves to be Cuneu with his curious ideas of pouring electricity like a liquid into a bottle. Just as it is impossible to pour a quart of milk into the pint bottle, so it is impossible to pour more than a certain amount of electricity into a conductor. Each conductor can hold a certain amount of electricity at a given electrical pressure and no more. Unless you can make the conductor more capacious, that will be all it is capable of holding.

But unlike the milk bottle we *can* make the conductor more capacious. The Leyden Jar is a way of making a conductor hold more electricity than it would normally. One plate of a Leyden Jar is charged with more and more electrons, that is a greater and greater charge of negative electricity; and the other plate gets an equal positive charge owing to the lines of force working through the glass between. These two charges will be held on the two plates until we make a pathway round for them to pass along and even themselves out round the circuit. Now without the device of these two plates separated by a non-conducting gap, a condenser, as we learned to call it, the electrons would have started round long before and the current would have been feeble.

All this we have seen, but a new picture of it will help to fix it in our minds. In Fig. 38 there is a glass tube. In the right-hand half there is water and in the left-hand half there is ink. At X there is a dam made of rubber which separate the water from the ink. There is a pint of liquid on both sides and the line Y marks the point to which the pint of water fills the tube. Unlike the pint bottle this tube can be made to hold

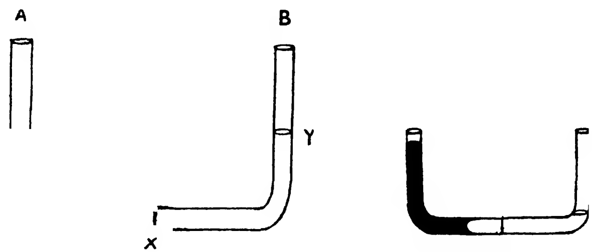


FIG. 38.—At X is a rubber dam. The picture shows how a condenser works.

more than a pint of water in it without the water reaching above Y. If you suck the tube at A, you will draw up the ink and the rubber will be strained to the left, allowing an amount of water to pass along into the other side of its bulge. The level of water will now be below Y and you can fill up to Y with the same amount of water as you have displaced by suction (Fig. 38, B).

You could also do the same thing by putting

a little more water in at B and pushing it down to the level Y with a ramrod.

Now if you suck too hard or push too hard you will break the rubber dam and the water and ink will be mixed.

All this is a simple picture drawn with things that you can see, of how a condenser works to increase the capacity of a conductor so that more electricity can be poured into it than it would ordinarily hold.

When you suck up the ink, it is a picture of what happens when you withdraw electrons from the left-hand plate of a condenser and charge it with positive electricity. When you do this there is an exactly similar charge of negative electricity on the right-hand plate.

When you ram down the water it is a picture of how you can charge the condenser by adding electrons, negatively charging it in fact; immediately the other plate loses electrons and becomes positively charged. When you do either of these things you may break the rubber non-conductor between the water and the ink, and this is a picture of how, if you overcharge the plates of a condenser, you may destroy the insulating quality of the space between them and thereby ruin the condenser and probably several other parts of your circuit as well.

There is one other point that we can see very

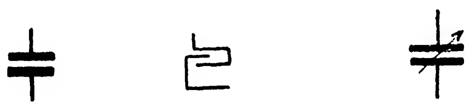
clearly from the glass model we have been using. A direct current is stopped by a condenser, but an alternating current is not. Why is this? No electrons can leap across the space between the plates of a condenser, the dielectric as it is called; they must come to a dead stop on the plate, where they continue to strain with their lines of force across the dielectric. They can only cross by destroying the condenser altogether. In our water and ink picture you see this clearly, you cannot go on sucking at one end or pushing at the other and hope to remove the liquids from the tube; you cannot get the ink out, let alone the water, until the rubber breaks. And so the ink and the water come to a dead stop directly the rubber has been strained to the limit.

But if you sucked and pushed alternately at either end the movement would act right through the rubber and you could keep up a movement of both ink and water for as long as you liked. The rubber bulges first one way, then the other, and though no liquid passes through all the liquid is kept in motion.

With these pictures in our mind we must return once more to capacity, and see how it acts to speed up the changes of an alternating current and see how it can be used to balance the slowing up of the changes by inductance.

VIII. A MECHANICAL OSCILLATOR WHICH HELPS US TO UNDERSTAND HOW INDUCTANCE AND CAPACITY WORK IN A WIRELESS CIRCUIT

We have seen in Fig. 34 the conventional sign for two coils inductively coupled ; here (Fig. 39) are the signs for a fixed capacity or condenser (*a* and *b*) and a variable one, while Fig. 40 is a



a b c

FIG. 39.—The signs for a condenser in a wireless diagram.

picture of what a variable condenser looks like in a set.

Fig. 41 shows a circuit containing a fixed condenser, C, that is, a fixed capacity, and a fixed inductance or coil marked L. SG is a spark gap and lines lead from the sides of the spark gap to a sign A at the extreme right, which is the conventional way of showing that there is a machine charging the circuit with an alternating current. This drawing is a *conventional* one ; that is to say, it is not in the least like what you would see if you tried to make the circuit. You might want to join the parts in quite a different way ;

it would make no difference; the diagram stands for any and all circuits having inductance, capa-

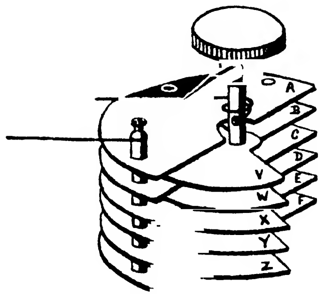


FIG. 40.—A variable condenser.

city and a spark gap. You must be ready to recognize it even when it is complicated with other things.

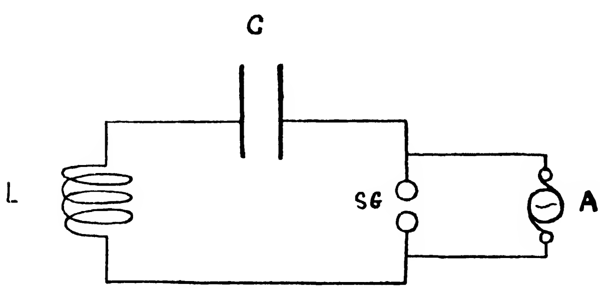


FIG. 41.—A diagram of a circuit with inductance, capacity, a spark gap and an alternator.

Having got the idea and the picture of this circuit well into your head, look at Fig. 42. Here we have a very simple mechanical oscillator. It

is made of a steel spring, an old-fashioned stay-bone would do splendidly, and a weight, fixed into a horizontal board.

In Fig. 42, *b*, we have the weight hanging normally from the steel spring. We draw the weight to one side as in *a*, and then we let it go. The weight oscillates between the three positions *a*,

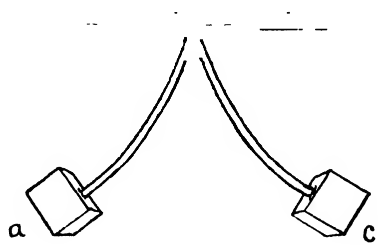


FIG. 42.—A weight hanging from a springy piece of wire, which forms a mechanical oscillator.

b, *c*, until at last it comes to rest at *b*. What are the forces that produce these oscillations?

We are going to examine them very thoroughly and we will begin by taking most of the oscillator, simple though it is already, away. And I hope that you will make the oscillator and play with it while you read so as to verify each point as I make it.

First I am going to suppose that there is a

table under our oscillator so that when the weight is at *b*, it only just misses it. Now let us draw the weight to position *a*, and then let us exchange the spring for a bit of string! And having exchanged the spring for string, at the very moment that we let go the weight let us cut the string away. What happens to the weight? It drops to the table. As we have cut the string, the only force working on it when we drop it is the force of gravity, and so it falls the distance that it is above the table, and of course it keeps on falling until it is stopped by the table. Very dull and obvious perhaps; but now tie the weight to the string and let go; what forces are acting on it now? Still its weight; it is up in the air and it will fall as low as it can by the quickest route. Owing to the string holding it the quickest way for it to reach the lowest level is to fall, not straight down, but back to *b*. When it gets to *b* it cannot fall any lower, for now its weight is balanced by the pull of the string, just as it would be if we had left it alone at *b* in the first place. So what does it do? Stop still? By no means; for though gravitation and the pull of the string cancel one another out, there is now a third force come into action, inertia, the force whereby a moving body *keeps on moving*, and so inertia carries it on to *c*.

Having got all that quite clear, let us get rid

of the string and put back our spring. Let us pull the weight back to *a* again and let go. The weight will rush back to *b* now quicker than if it was hanging from string, because a new force has come to lend a hand. This force is the energy stored up in the spring when it is wound up or bent out of its normal shape or position.

When you push the weight back to *a*, you have to use more energy if it is hanging on a spring, than if it were hanging on a string, because you have to use some energy to *deform* the spring. This energy is not lost, it is stored up in the spring, and when you leave go, the spring uses this *potential energy* to get straight again ; and so the spring pushes the weight on in a hurry, whereas the string just bent with the weight, having no particular desire to be at *b* rather than at *a*.

Now consider these two forces as the weight oscillates back and forth. At *a* the weight is without motion for a moment and so has no energy of motion ; its inertia would rather have it remain without moving at all. But at this point the spring has most energy, because it is most deformed. At this moment, then, it is the energy of the spring that is responsible for the oscillating (apart from the desire of the weight to fall, which need not bother us at the moment). When the weight gets to *b*, the situation has

completely changed; the weight being in rapid motion wants to go on, but the spring being nice and straight has no energy at all to go on; it would rather stay where it is. It is then the inertia of the weight that carries it on to *c*. But on this journey the spring has been more and more deformed again, and therefore is gathering more and more potential energy, while the weight

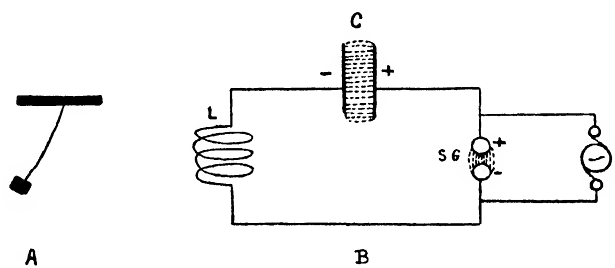


FIG. 43.—A comparison between how electrons behave in a circuit with inductance and capacity and how a mechanical oscillator behaves. Part 1.
(This drawing and the next two are based on drawings in the Admiralty Handbook.)

is losing the energy of its inertia until, at *c*, it has none at all. At *c*, when the energy from inertia is zero, the potential energy in the deformed spring is at its maximum, so back goes the oscillator, thanks to the spring; and so on and so on and so on.

Now if you have been patient all this time you are going to be rewarded.

Look at Fig. 43. On the left you have your

mechanical oscillator charged up by the spring having been deformed. On the right you have your electrical oscillator with the condenser charged up to just too small an amount to set the electrons moving across the spark gap. There is potential energy in the deformed spring wanting to get straight. There is potential energy in the electrons straining to get across the spark gap and even themselves round the circuit. There is no energy in the weight, because it is

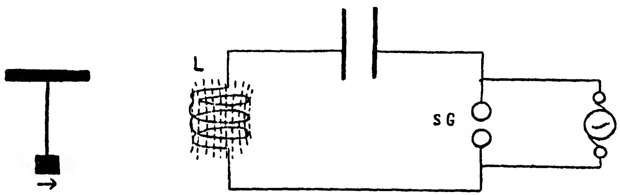


FIG. 44.—See the last drawing. This is Part 2.

at rest, and there is no energy in the inductance, because there are no electrons moving in the circuit.

Next look at Fig. 44. You have let go the weight and the mechanical oscillator has moved to the right. You have discharged the circuit across the spark gap. There is now no potential energy in the spring, because it is not deformed, and there is no potential energy in the condenser, because it has been discharged. But there is now energy of inertia in the weight, because it is moving,

and there is energy of inertia in the inductance, because electrons are moving round the circuit.

We come now to Fig. 45. The mechanical oscillator on the left has reached the farthest point in its swing to the right. The spring has been fully charged with potential energy, and the weight has lost all its energy of movement. In the electric oscillator exactly the same thing has happened. The condenser has been fully charged

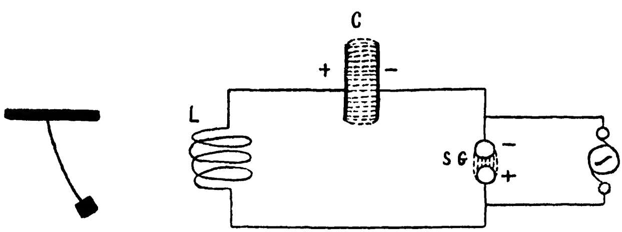


FIG. 45.—See the last two drawings. This is Part 3.

with potential energy from the alternator; and the inductance has no energy because the current has momentarily died down, leaving the electrons at rest round the circuit. The only difference from Fig. 43 is that now the condenser is charged in the opposite way. If it had a surplus of electrons on its right-hand plate before, it now has a deficit, so that the current, when it starts across the gap, does so in the opposite way round the circuit. *And this is as it should be to make our two pictures perfectly coincide*, because now, in

our mechanical oscillator, the swing is also in the opposite direction.

And now, thanks to our mechanical models and rough pictures of things we can see, we have learned enough about the theory of wireless to be able to understand some real electrician's diagrams; and to follow in the diagrams the history of our wireless sets from the beginnings to the present day.

Resonance, inductance, capacity, be sure that you know what these mean and you will have no difficulty from now on.

CHAPTER VII

HOW THE WIRELESS WAVES ARE CAUGHT

I. WE BUILD UP THE IDEA OF AN AERIAL CIRCUIT FROM A CLOTHES LINE IN THE YARD. HOW THE AERIAL GOT INTO THE AIR, AND WHY MARCONI PUT IT THERE

A MODERN wireless set has to do several different things. First, it has to catch the waves out of the ether and be made to vibrate by them in exactly the same way as the transmitting station is vibrating; second, it has to turn these rapid oscillations into something that we can hear; third, it has to amplify the oscillations so that when they are turned into sound waves by some method or other, they are also made far more powerful; fourth, it has to select one set of wireless waves coming from one station and cut out all the other waves from the other stations.

Of course, this is a far more complicated task than what Hertz had to do with his Resonator, content as he was to see a tiny spark at a distance

of a few feet from his Oscillator. But now that we have a clear idea of the theory, which is the same in both cases, all we have to do is to fill in the details.

First of all, the maker of the modern wireless set does not try to do all the tasks with one circuit, as Hertz did. You have seen how, thanks to induction, currents can be transferred from one circuit to another; and in the modern wireless set there are many circuits each "inductively coupled" to the next, and each one of these circuits does its own particular job.

The first circuit is of course the one that receives the wave sent out by the transmitting station and it is called the aerial circuit. Fig. 46 shows on the left hand the conventional sign for all the things that this circuit contains, and on the right hand a picture of each part to help you understand it immediately.

Let us run over the parts together. First there is at A an aerial. Any sort of aerial you may care to choose (except a frame aerial such as is used in portable sets, and they have a different sign and work somewhat differently).

B you will recognize as a variable inductance or coil to add as much electronic inertia as you may want when you tune the circuit. C you also know; it is a variable capacity or condenser to alter the amount of capacity, or springiness, in the

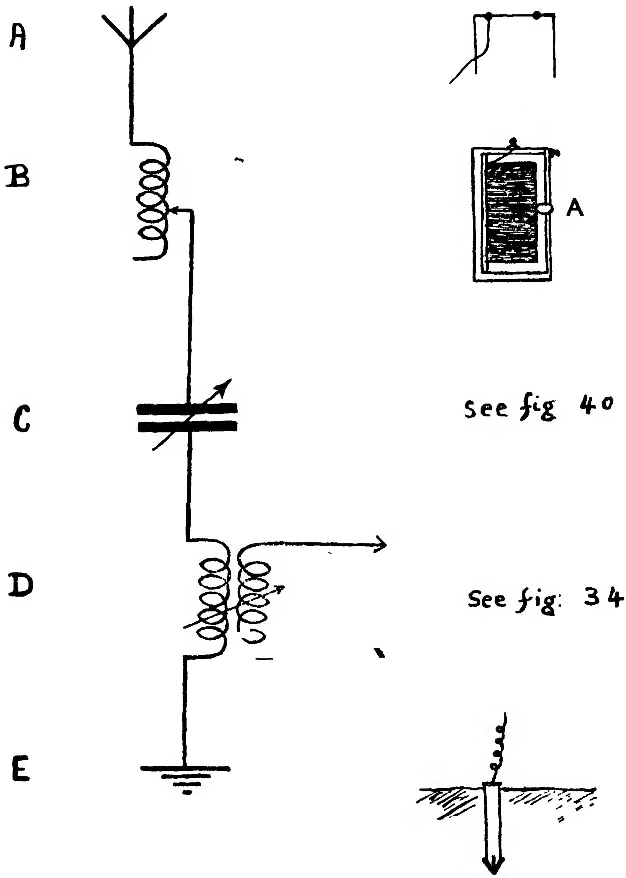


FIG. 46.—An aerial circuit. On the left the signs used in diagrams ; on the right what the parts look like.

circuit to suit your tuning. B and C together settle the LC value of the circuit.

D is an inductive coupling, by means of which electron movements started in the aerial circuit may be carried off to another circuit, there to be used for other purposes. E is the earth lead which offers a path to the electrons which rush alternately down into the earth and up from the earth when the aerial is being charged with an oscillating current by the ether waves.

There is nothing here that you do not understand, and yet you may not at first sight see that this is nothing more than a complicated form of Sir Oliver Lodge's Syntonic Jars. Let us make this picture of an aerial circuit even simpler. Remove from it B, C, and D. You have nothing left now but the aerial wire and the earth beneath it. But even this is not so very different from a Leyden Jar! Let us forget all about aerials even, let us think about clothes lines instead. There is a wire clothes line hung up in the back garden, nothing more; and even now you have a condenser, just as certainly as if you had a Leyden Jar in the back garden. One plate is the wire clothes line, the other the piece of earth immediately beneath. If you charge the clothes line with a negative charge, that is if you pour into it a crowd of surplus free electrons, then they will strain across the gap between the line and the earth and

push away an equal number of electrons from the earth surface deeper into the earth.

Why do we not simply join up the clothes line to the earth and put in some coil by which we can couple the circuit inductively to a circuit containing a detector? Well, we very nearly do. The only difference between this clothes line circuit and our aerial circuit is that the first is not tunable and the second is.

It is important to think about this because then you will see the action of the aerial circuit quite clearly. You will see that the aerial circuit is nothing but Lodge's Syntonic Jar, with the spark gap removed and some other means of detecting the electron flow inductively coupled through to another circuit.

There is, however, one great difference between our aerial circuit and any other condenser we have seen so far, and that is that one of the two plates has been stuck up in the air. The Leyden Jar has its plates very close together; the Hertzian Oscillator increased its radiating power by having its plates put far apart. In the modern wireless sets and in the modern wireless transmitting stations the plate has been stuck on top of a pole. Who made this change and why did he do it?

This question brings us to the third great name in the history of wireless; first, Clerk Maxwell

showed that wireless waves ought to exist ; second, Hertz, by opening up his condenser, actually found them ; and third, by sticking the condenser plates farther apart still, MARCONI made wireless waves useful to mankind.

It was in 1894, when Marconi was less than twenty-one, that he began to carry out his experiments. He had learned about Hertzian waves at the university and at once determined that he should be the one to take them out of the scientific laboratory into the world of men. Instead of being content, as Hertz had been, to show that Clerk Maxwell was right, he was determined to make this knowledge useful.

He began with apparatus very like that of Hertz, except that his spark gap was better arranged. From the very start he was determined that the signals should mean something, so he used the Morse dot and dash code, which was already in use for wired telegraphy and was just as suitable for the wireless telegraphy of which the young Italian was already dreaming.

He inserted into his oscillator a key, just like our old friend the drawbridge for a bell circuit, so that he could make and break the current in the circuit as often as he wished. When he pressed it down and up quickly a very short train of sparks passed and sent out waves which made the resonator at the other end of the room spark too.

When he pressed down for a longer period, a longer response came from the resonator.

This was all very well in its way, but it was not of much practical use, so Marconi took his apparatus out into the garden. He wanted to be able to detect the waves over longer distances and the problem was how to do this.

At this time he had not thought much about tuning and he did not profit by Sir Oliver Lodge's syntonic jars. He thought more about improving the Oscillator than the Receiver and naturally enough thought about increasing the distance between the plates of the condenser. Hertz had improved on Leyden Jars for radiating by widening the distance between the plates, and now Marconi took a hint from a Russian scientist named Popoff and stuck one plate on the end of a pole and the other flat on the ground.

At the other end of the garden he set up a similar receiving aerial and he soon found that the higher in the air the aerial was put, the farther he could signal. If the aerial was put on a pole two metres high, he could receive signals over a distance of thirty metres; if it was four metres high, over a distance of a hundred metres; and if eight metres high, over a distance of four hundred metres.

Thus it is that both wireless transmitter and receiver have changed in the course of their history from Leyden Jar to Hertzian open oscillator,

to Marconi's elevated aerial: always a widening of the plates of a condenser, but, however disguised, always a condenser.

II. ANOTHER WARNING ABOUT WORDS. HOW TO CHANGE A CLOTHES LINE EARTH CONDENSER INTO A TUNED AERIAL CIRCUIT

Turning back to our diagram of an aerial circuit, let us consider the variable inductance and the variable capacity. At the beginning let me warn you about the use of these words. We have seen that a coil of wire with or without a piece of iron in the centre adds to the self-inductance of a circuit. Because of its shape more lines cut across the circuit when it is wound into a coil than if it were a straight piece of wire. Now because the way to add self-inductance, or, as we call it for short, inductance to a circuit, is to add a coil, very often electricians call the coil itself an inductance. They add inductance by adding an inductance in other words.

In the same way they speak of adding capacity by putting in "a capacity", which is, as you see, nothing else but a condenser. BUT, and here comes the likelihood of misunderstanding, when you add a capacity, or a condenser, to a circuit, you will in most cases *reduce* the capacity of the circuit. That sounds complicated, if not quite silly, but the only difficulty as so often is in the

bad use of words, and we shall have no difficulty in straightening it out in a moment.

The variable inductance and the variable capacity are put into the circuit to tune it. We have already learned that the " LC " value of the transmitting set and of the receiving set must be the same for them to be in resonance with one another. Now we also know that the wire of the aerial and the surface of the earth beneath are two plates of a condenser. The capacity of this condenser will always be too great and, if you did not reduce it, you would find that the LC value of your aerial circuit would be so great that you could not tune in any wave length that is commonly used in wireless.

And so you put into the circuit a thing like Fig. 40. The plates marked A, B, C, D, E, F, are all joined together, and so are the plates V, W, X, Y, Z, and the two sets are insulated from one another. By turning the handle you can arrange the two sets of plates so that they either completely overlap one another or hardly overlap one another at all. In the drawing the handle has been turned so that about two thirds of the plates overlap.

The only reason why there are all these plates is to save space, they act very much as if A, B, C, D, E, F, were all one plate joined end to end and the other set of plates also one plate. You could

make a variable condenser in the shape of a Leyden Jar if you slid the inner and outer plates up and down so that a different amount of each lay opposite to the other; the principle is exactly the same.

Next we will look at the variable inductance in Fig. 46. It is a coil of wire wound round a piece of wood and there is a slide along which the pointer A moves. By moving A we can include in the circuit a varying number of twists and so vary the self-inductance of the circuit. As it has been drawn, about half the twists are in the circuit and the rest at a dead end; by moving A to the right more, and by moving it to the left less twists and therefore inductance would be added to the circuit.

It will be very good practice for you to redraw Fig. 46 with all these parts joined together in a circuit. And as you look at this circuit let us sum up the points we have learned about how it works.

1. The aerial wire and the earth beneath are two plates of a condenser which will be charged negatively and positively by the electromagnetic waves coming from a transmitting station. (This is also true of a wire clothes line, or telegraph wires or any other conductor lying parallel to the earth. The only reason why you do not hear a crooner's voice coming from your line on washing day is that it is not properly tuned and it has no

means of detecting the vibrations set up in it by wireless waves. But unknown to mortals the crooner croons in every clothes line in the world.)

2. So that the oscillations set up by the wireless waves shall be as strong as possible, the aerial-earth must have inductance and capacity added to their natural inductance and natural capacity so as to bring up the total inductance-capacity of the circuit to a value LC equal to the LC of the transmitting station.

3. Of course the inductance need not be the same as the inductance of the transmitting station, nor need the two capacities be the same. What is necessary is that the two multiplied together be the same.

4. We arrange to bring this about by adding to the circuit the two pieces marked B and C, that we have been studying.

5. We should not forget that besides the inductance and capacity of the circuit there is another factor ;—the resistance. We have seen enough about this to know that what we have to do is to keep the resistance of the circuit as low as possible. For example, we shall not use a hundred yards of wire in order to join one part to another when one yard is enough.

6. When we have done all this, we have only arranged to receive the wireless waves in the best conditions ; we have done nothing to make the

waves noticeable to human senses. We cannot see, hear, taste or smell them. That is the business of the detecting circuit, which is coupled to the circuit we have been studying so far by the coils marked D in the diagram.

There are two other things that we have not yet mentioned, and since they need a good deal of mathematics to understand we will be content with just stating them as facts.

7. Not only do we want to tune in the right wave, we also want to tune out all other waves that may possibly interfere with it. To do this we see, among other things, that not only is LC right, but that L divided by C is the largest possible amount. I think that this will be perfectly clear if we imagine three different circuits A, B and C all of which have the same LC value and yet different L and C.

	Inductance (L).	Capacity (C).	L.C.	L/C.
A	100	1	100	100
B	50	2	100	25
C	10	10	100	1

If three such circuits did exist then the first would be the best for tuning purposes, for not only would it receive the right wave just as well as the other two, it would refuse to receive any other wave far better.

The last point to trouble us just at present is this matter of words to which I referred a few pages

back. Here is a sentence that sounds untrue :—If you add inductance you increase the value of LC, but if you add capacity you decrease the value. I remember that when I first read such a statement I was muddled and annoyed at it, because it did not seem possible that it was true. Then I remembered the difference between *capacity* and *a capacity*. As it is a point that even good text-books often state in a very confusing way, let us devote a dull, thorough section to it.

III. QUITE THE DULLEST SECTION IN THE BOOK, AND YET ONE THAT MUST BE CHEERFULLY BORNE

Here is a sentence from one of the very best wireless text-books : "Unless the LC value of the incoming wave is the same as the LC value of the receiving aerial itself, we shall have to add inductance in series to increase the LC value, or else capacity in series to decrease the LC value, and so make the aerial a resonant circuit."

The secret is that by *adding capacity* we do not increase the capacity of the circuit but decrease it. We will look at four simple drawings of aerial circuits, which will put this all straight.

In Fig. 47, A, we have an aerial and an earth connected with two *capacities in series* ; in B we have

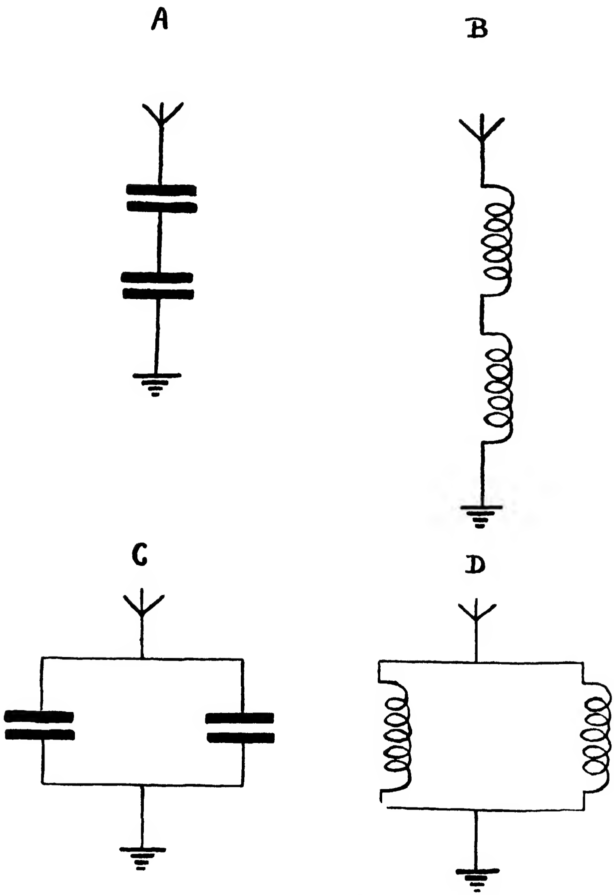


FIG. 47.—Some more simple diagrams of aerial circuits.

them connected with two *inductances in series*; in C with *two capacities in parallel*; in D with two *inductances in parallel.* You have only to look at the four diagrams to understand once and for all what is meant by "in series" and "in parallel".

Now these are the rules for finding out what effect is produced on a circuit by these four arrangements.

(A) Two capacities (or condensers) in series. (Before starting let me explain a mathematical term: the reciprocal of a number is one divided by that number; thus, for example, the reciprocal of four is one divided by four, that is a quarter.) Condensers are measured in a unit called in honour of Faraday a microfarad. Let us suppose that we have put two condensers in series, one having a capacity of four microfarads and the other of two microfarads. Add together the reciprocals of 4 and 2 and you will get the reciprocal of the capacity added to the circuit. That nasty sentence boils down to $\frac{1}{4} + \frac{1}{2} = \frac{3}{4}$ = the reciprocal of the added capacity; and $\frac{3}{4}$ is the reciprocal of $\frac{4}{3}$ or $1\frac{1}{3}$.

So that two condensers of four and two microfarads in series are the same as one condenser of $1\frac{1}{3}$ microfarads. Now suppose one of the two condensers is the aerial earth with a capacity of four, you will see how adding another condenser

to the circuit reduces the capacity, and therefore the LC value.

(B) Two inductances in series;

this is much simpler, I am glad to say. A coil adds inductance to a circuit by reason of the number of magnetic lines of force cutting the circuit from the twists making up the coil. Increase the number of twists and you increase the inductance, so that to get the value of two inductances all you have to do is to add their separate values together.

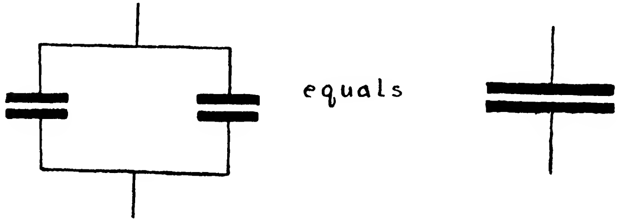


FIG. 48.—The rule for capacities in parallel.

(C) Two condensers in parallel;

very easy indeed, and exactly the same as (B). Two condensers in parallel are just the same as if they were one twice as big, or put into a pictorial form Fig. 48 states this in the easiest possible way.

Since a condenser is often called a capacity you will often find in careless text-books a sentence like this: "The total capacity of two capacities in parallel is the sum of their separate capacities." But even that will not muddle you now.

(D) Lastly, two inductances in parallel. Exactly the same as the rule for condensers *in series* ; so we need do no more than state it without further explanation. " The inductance of two inductances in parallel is found by adding the reciprocals of the inductances of the separate inductances. The result is the reciprocal of the total inductance of both together." A nice sentence which I am glad to say has no terrors for you.

All of this is in my opinion very dull. But you cannot hope to understand anything at all unless you can learn to keep your attention from wandering even when faced with dullness, compared with which ditchwater is a blaze of jumping electrons and bursting atoms.

IV. HOW TO ARRANGE PRACTICAL AERIAL CIRCUITS AND HOW TO DRAW THEM. THE ACCEPTOR AND REJECTOR CIRCUITS AND OTHER SIMPLE COMBINATIONS

If you have followed all that we have seen so far you have now got to a stage where you can understand anything there is to know about an aerial circuit. All that remains is built up out of these quite simple facts.

There is one other point that we must consider before we pass on. We know how to get our wireless wave and we know what the aerial, the

earth, the variable condenser, the variable inductance, and the coupling coil do. We might think therefore that Fig. 46 is a full diagram of the aerial circuit of any set. As a matter of fact there are dozens of different aerial circuits, all of them built out of the few simple parts we have been studying,

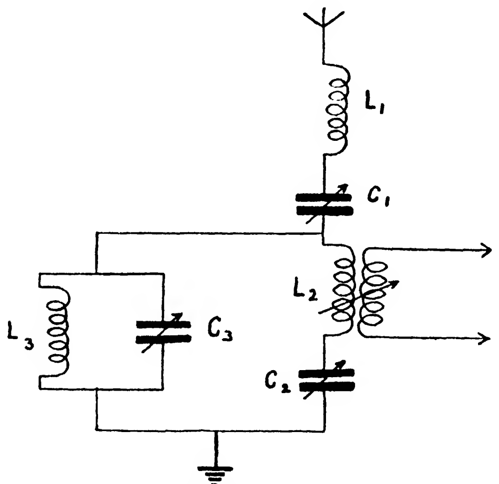


FIG. 49.—A more complicated diagram of a quite imaginary aerial circuit.

but all fitted together in different ways so as to improve the results obtained from them.

I am going to give you one example of how an aerial circuit may be arranged, so as to be very much more efficient than the simple affair shown in Fig. 46, at least in theory.

In Fig. 49 we have an aerial circuit made up of

three inductances and three condensers. Let us consider it in three separate parts ; first, there is L_1 and C_1, nearest the aerial. They are, as you know, an inductance and a capacity in series. Then there is L_2 and C_2 on the right-hand side of the diagram lower down. Again we have an inductance and a capacity in series. We note that this second inductance is the primary coil of a couple which leads to the detector circuit, which we are going to study later.

Both these parts of the circuit we have met with before and thoroughly understand. We notice that the inductance is fixed, but that the capacity is a variable condenser, and so we know that by varying the latter the LC value is made to equal that of the wireless wave we want to capture. When the tuning has been done the aerial circuit will offer an easy path to the right wave and a difficult one to all the others. Still nothing new, except that the parts have for some reason been doubled. But now look at the remaining parts. Another inductance and another capacity, this time *not* in series, but *in parallel.* And here lies the cunning of this circuit !

Suppose that a wireless wave starts this circuit oscillating, and suppose that it is tuned so that the LC value of both the wireless wave and the circuit are the same ; a most important result will follow. Part of the oscillation will pass to the left at the

point A and will be forced to act through the condenser. As we know, the condenser will act like a spring and hurry the current on. The rest of the current will pass to the right and act through the inductance ; and, as you know, the inductance will act like inertia and hold the current back. If the circuit is properly tuned the part that will be hurried on and the part that will be held back will block one another and there will be no oscillating at all from the wave to which this circuit is tuned. In fact, just as an aerial circuit with an inductance and a capacity *in series* accepts the resonant wave and holds up all others, so the aerial circuit with an inductance and a capacity *in parallel* rejects completely the resonant wave and allows a path to all other waves, and the more so the more they are out of resonance.

One word more about Fig. 49 ; we have here an aerial circuit with both an " acceptor " circuit and a " rejector " circuit. I do not suppose that there is a receiver in the world that actually has such a combination as this. For one thing some of the parts would be most unwieldy, and for another it would not work in practice. Probably the coil of the rejector circuit would have to be an exceedingly thick copper ring of one turn or so weighing about forty pounds, and also it is not really possible to treat the three circuits included in the figure as if they were quite separate. Their in-

ductance and capacity effects would " lump " into one and bring all sorts of complications. But it will be worth while discussing this diagram as if it could be used in practice, because it will help to make us clear about inductance and capacity.

Suppose there are two stations one sending out a wave of three hundred metres and the other a wave of four hundred metres. Suppose also that you want to listen to the shorter waves, but the longer one interferes with you ; what can you do ?

You tune your three sets of inductances and capacities so that they have the LC value of the wave that you want to detect. The electro-magnetic fields of the two stations rush through the ether towards your aerial circuit, but when they get there they meet with quite different treatment. The three-hundred-metre wave finds two acceptor circuits tuned to receive it, and one rejector circuit tuned to reject it. There is no path at all for it down the left-hand side of the aerial circuit, because that path is completely blocked by the rejector circuit ; so all the oscillation from this wave goes down the right-hand side and through the inductance which is coupled to the detector circuit. Meanwhile the four-hundred-metre wave finds the two acceptor circuits out of resonance with it, and therefore offering a very bad path for its oscillations ; but what gets through the first acceptor circuit finds a ready path through the

rejector circuit, takes it and oscillates between it and the earth without any of it passing through the coupling and being passed on to the detector circuit. As a result you can hear the three-hundred-metre wave without any interference from the four-hundred-metre wave.

There are several other ingenious ways in which the simple facts we have learned can be used to provide good selective aerial circuits. It is a very good plan to draw possible circuits for yourself. For example: how would you solve this problem? There are two near-by stations one tuned to send out waves of four hundred metres the other of six-hundred-metres; how could you tune out the six-hundred-metre wave by using three acceptor circuits in your aerial circuit? (By the way, you see here another example of bad wording common in wireless text-books, the acceptor circuits are really not complete circuits at all but bits of the one and only aerial circuit.)

The last circuit that we looked at tuned out the interference by using a rejector circuit, but now you are asked to use all acceptor circuits, that is, as you know, all three sets of inductance and capacity *in series* and none in parallel. If you have drawn the circuit right your diagram will look like Fig. 50. Circuits A and B are tuned to be in resonance with the wanted wave; and circuit C is tuned to be in resonance with the inter-

fering wave. Then whatever of the interfering wave gets through circuit A will then oscillate through C, which has its own separate earth and is not coupled with the detector circuit.

Suppose now you wanted to be one step more elaborate still, and have a circuit which will tune

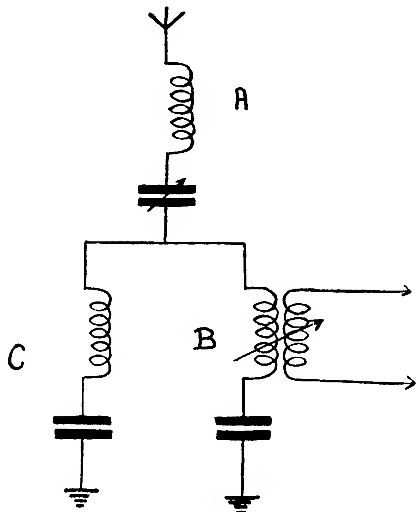


FIG. 50.—How to get rid of an interfering wave.

in first one wave, then the other, and in each case will tune out the unwanted wave, how would you arrange your three acceptor circuits? You could do this by tuning circuit A alternately to either wave, and by having both B and C coupled to the detector circuit, with a key inserted between each coupling and the rest of the detector circuit so

CHAPTER VIII

HOW THE CAPTURED WIRELESS WAVES ARE DETECTED

I. HOW GUITARD SAW THE DUST IN A SUNBEAM SPINNING ITSELF INTO ROPES; *AND HOW* THIS LED TO THE INVENTION OF A FAMOUS LIGHTNING PROTECTOR

YOU will remember that, long before Hertz or Clerk Maxwell, wireless waves had been giving themselves away by producing sparks between more or less distant conductors. That was what Adams described in his *Essay on Electricity* so long ago as 1780; that was what had sent Elihu Thomson running upstairs in the school in Philadelphia; that was how Sir Oliver Lodge detected them with his Syntonic Jars. Now we have got a very long way from those days; we have changed from what is called spark transmission and the detection of the signals by sparks to the most amazingly accurate wireless telephony, which transmits complicated musical sounds, so that we hear them practically as perfectly in our own homes as in the concert hall.

In this chapter we must see how this has come

about; and especially must we learn to understand two great inventions, the telephone and the microphone. We are going to see what happens in that at present mysterious secondary circuit to which we know the oscillations caught by our aerial circuit have been shifted by induction. We have seen exactly how that current was shifted; we have followed the way in which the electrons moving in the twists send out their lines of magnetic force; we know that these lines of force cut across the secondary coil and set up a second current in the new circuit; we know that we can step up or step down this current by altering the number of twists in the secondary coil; but we know that the changes in the original oscillations will be faithfully reproduced in the coupled circuit, so that the exciting passage from transmitting circuit to wireless waves to receiving aerial circuit to secondary detecting circuit leaves us with the exact oscillations from which we started. All this we know; but this is what we do not know—how this unchanged oscillation can now be changed into something that we can hear.

The story begins with a man for whom I hope you have some very sympathetic feelings, Professor Hughes, who walked up and down a London street with telephones clicking at his ears; Professor Hughes who was so shamefully sat on by the bigwigs.

Hughes is the inventor of the microphone, and on the very day that he accidentally hit on the clicks from ether waves, he was actually experimenting with microphones. He was also testing a piece of apparatus called an induction balance. We need not worry here as to what an induction balance does or is; the important thing about Professor Hughes' induction balance from our point of view was that it *would not* balance at all.

At first Hughes thought the insulation must be wrong, but at last he discovered a loose joint in his circuit that was sparking. I imagine that you have yourself discovered loose joints or contacts from time to time, if you happen to keep in your house any lamps, curling tongs, electric kettles, toasters, irons or fans, which have to be plugged into a socket in the wall. The plugs get bent and do not fit properly and the result is heating, sparks and perhaps burning cotton or rubber. You know why; it is because the loose connection is setting up a huge resistance to the current, so that the moving electrons are bashing the copper molecules about mercilessly.

Hughes was particularly interested in loose contacts and connections and joints because—and note this carefully—that is all that a microphone is, a loose joint. So he decided to experiment with his chance loose contact and see if it was any good as a "microphonic joint". And it

was while he was arranging to do some experiments that the telephone most surprisingly began to click. It is part of the hard luck of Hughes' story that he not only discovered ether waves before Hertz without being able to convince people, but used a detector which was far better than the one used by Hertz later.

Hertz relied on the electromagnetic field from his Oscillator cutting across his Resonator and producing a current which would be strong enough to jump a spark gap. That meant that the electrons moving in the Resonator had to break down the air atoms into ions and force a path through them from one side to the other of the gap. Now there was already known a much better way of doing things than this, a way which had been discovered like so many other things, by accident.

A Frenchman named Guitard was experimenting with an electrical machine one sunny day in 1850. A bright shaft of light came in at one window. You know what a shaft of sunlight always reveals : that the room is far dustier than one would think. Up and down in the sunbeam floated billions of motes. The electric machine began to spark ; immediately Guitard noticed a surprising result ; the motes in the sunlight had suddenly arranged themselves into a series of ropes. The machine stopped and the motes fell apart and continued their haphazard floating.

Every time the machine sparked the same thing happened. In fact what Guitard had discovered was, when the scientists had had time to give it a sufficiently long name, that the dust in the room was acting as a " self-restoring coherer ". That is to say, that under the influence of near-by moving electrons, loose specks of dust cohere or stick closer together, and when the electrons stop moving, they fall apart again or decohere.

At first sight that may not seem a very useful discovery, but it has played an important part in several of the most useful of modern electrical inventions.

Sixteen years after Guitard's accident with a shaft of sunlight the first practical use was made of this principle of coherence. Telegraph circuits were often in danger from lightning; at any moment in a storm they might be struck, and a violent electron movement be set up in the wires strong enough to fuse them and destroy delicate instruments. A scientist named Varley saw that if particles of dust or powder were put in a tube and the tube included in the telegraph circuit protection from lightning would result.

He connected up the telegraph wire to the earth through such a tube or coherer, as it was called; and the power in the coherer was arranged in such a way that it offered a very high resistance to ordinary electric currents. That is to say, that

when electrons moved in the telegraph wire to produce an ordinary telegraph message they could not trickle away to the earth through the coherer because they were not strong enough to break down the resistance ; but when a storm of electrons set in motion by a flash of lightning came hurtling through the wire they could break down the resistance in the coherer by forcing the particles of powder to cohere and thus find a safe path to the earth.

It was this principle of coherence that Hughes used for his accidental discovery of ether waves ; it was this principle that later Sir Oliver Lodge suggested as suitable for their detection and that Marconi finally used for his most important early experiments.

II. HOW MARCONI USED THE SAME PRINCIPLE OF COHERENCE TO DETECT WIRELESS WAVES

It was in 1889 that Sir Oliver Lodge saw that a coherer could be used far more effectively than Hertz's spark gap for the detection of wireless waves. He put the balls in his Resonator so close together that only the tiniest film of air lay between. Then when the electromagnetic fields swept outwards from the Oscillator the two balls cohered just as if they were motes of dust, and let the current pass round the circuit to be registered somewhere else in the circuit by a galvano-

meter. After each signal the balls had to be gently tapped to make them separate and then they were ready for the next signal.

Next year, 1890, another Frenchman profited by Guitard's accidental discovery and invented the Branly Coherer named after him. It was this Branly coherer that made Marconi's experiments so successful, and to him we will now return.

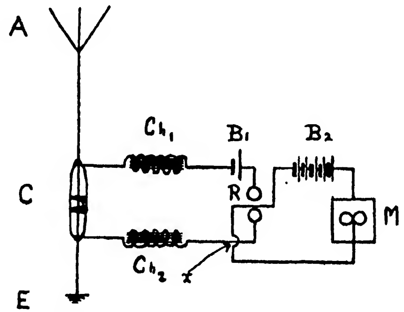


FIG. 51.—Diagram of Marconi's first receiving set.

We left him with one plate of his condenser up a pole in the garden, with the first aerial in fact. Let us now draw an early Marconi receiving and detecting circuit. Here it is in Fig. 51; there is very little in this drawing that you will not be able to understand without further explanation.

C is the conventional sign for a coherer. Notice the little loop drawn in the wire at x. This means that, although in the drawing the lines have to

be crossed here, the wires which the lines represent do not touch. There are then two circuits drawn; and they have some sort of mysterious connection at R, which we shall look at in a minute.

Imagine an electromagnetic field of ether waves forming and collapsing many times a second and cutting across the aerial A. The lines of force cut across the aerial circuit and start oscillations between the aerial and the earth. These oscillations make the metal filings in the Branly coherer, C, cohere so that a current can pass through. This makes a complete path for electrons to move round through the circuit containing C, Ch_1, B_1, R and Ch_2. Until this happens C is a drawbridge exactly like the one at the front door in the bell circuit which has been drawn up; the ether waves let the drawbridge down. Immediately the cell marked B_1 comes into play. (You recognized what B_1 stood for from what you read on page 37 and from Fig. 6.) The electrons piled up on the negative plate of B rush round the circuit directly the drawbridge is down and passing through Ch_1 and Ch_2 they reach the two round circles at R. What is R? (Ch_1 and Ch_2 by the way are, as you have guessed, coils to slow up the current changes by self-inductance.)

R is what is called a relay and you are going to recognize in it an old friend. It is nothing

else but our friend the electromagnet, which we first met in the bell unit and drew in Fig. 4. When the electrons moving round the circuit come to R they magnetize the iron bar and the bar pulls down a drawbridge arranged to close the second circuit which you see drawn on the right side of Fig. 51. When this circuit is closed, the battery of cells B_2 comes into play, sends a current round the circuit which comes to M, and M is any kind of registering machine, a bell, a Morse ticker, an earphone perhaps.

There is nothing complicated about the working of any of this. Compare the first circuit to the bell circuit in Fig. 4. The aerial is a new kind of button which is pressed not by a human finger, but by an ether wave ; the Branly coherer is the drawbridge let down at the front door ; the cell is the same in both circuits ; and the relay R is exactly like the bell unit except that it is not used to ring a bell but to close another circuit with its drawbridge.

You will perhaps wonder why there is any need for two circuits. Well, I think you will see why, if you look at B_1 and B_2. B_2 produces a stronger current than B_1, so that the current in the two circuits are of different strengths. The current in the first circuit is just enough to work the relay R and the current in the second circuit has to be stronger in order to work the recording device

M. In other words, the use of two circuits with different-sized batteries is just a convenient way of stepping up the original pressure, which could have been done by using coupled coils, as we saw in Fig. 46.

To be perfectly complete in our description of Marconi's receiving circuits we must add one important detail left out in the diagram. Unlike the motes in Guitard's ray of sunlight, the Branly coherer is *not* a self-restoring coherer. It has to be tapped after every signal to make it decohere and be ready for the next signal. To do this you have to introduce a tapper circuit into the other circuit. That is to say, you have to arrange that when the electrons move round the circuit which has been drawn in the diagram, they also do an extra piece of work on the side; they pass along wires connected to a bell unit without a bell. In this tapper circuit, when the electromagnet pulls down the drawbridge, the drawbridge pushes a clapper against the coherer, just as it pushes the clapper against a bell in the bell circuit. I want you to take a piece of paper and draw into our Fig. 51 the tapper circuit. You know everything that is required to do this and you will be able to see much better from doing this yourself than from any description.

You will notice that Marconi's circuit is not a tuned circuit. He had profited from Popoff and

put his aerial in the air ; he had profited from Branly and got a better detector ; but as yet he had not profited from Sir Oliver Lodge's Syntonic Jars. That came very soon, however. Fig. 52 shows the first Marconi tuned receiving circuit.

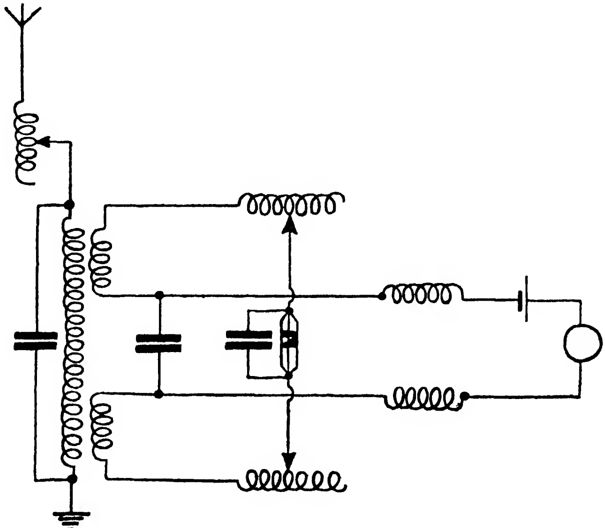


FIG. 52.—A diagram of the circuits through which Marconi received the first trans-Atlantic signals in 1901.

You will not be able to follow all of it, and, since no modern circuit is like it, I shall not complicate things by going into detail. But try to make out as much as you can ; and remember when you look at it that this diagram describes the most important single event in the whole history of

wireless, for it is connected with Marconi's famous patent No. 7777 of 1900, which lies at the very root of all modern commercial wireless, and *it was through this circuit that the first trans-Atlantic signals came in* 1901. Notice the variable inductances and the coupled coils and variable condenser. Notice that now the coherer is in a secondary circuit and not in the primary aerial circuit. Also notice that the diagram stops at the relay and does not include the circuit which contains the recording instrument nor the tapper circuit.

III. HOW A TELEPHONE AND A MICROPHONE WORK

You will have seen that the great difference between detecting oscillations set up by ether waves with a simple spark gap and with a coherer is that with the coherer you no longer use the actual oscillations to let your senses become aware of their presence. With the spark you actually see the oscillations sparking, with the coherer you use them to let down a drawbridge which will allow quite a different current, coming from a battery, to act on your eyes or ears. All the oscillations do is to work a drawbridge for a quite different current to pass over. It is a matter, too, of all or nothing; either the drawbridge is down and a current will flow, or it is up and no current will flow. It does not matter how the oscilla-

tions may change; the changes will never cross the drawbridge and come to our knowledge. Clearly some other way of detecting ether waves had to be invented before we could do more than listen to a mere succession of sparks. The easiest way to understand the new thing begins at your plugging in a faulty connection in a wall socket.

Suppose you have an electric light bulb which flickers when you switch it on. You will immediately try pressing it down tighter into its socket and then probably it will keep properly lit. Now what have you been doing? You have been varying the resistance to the current by tightening up a loose joint. The looser the joint the less current gets through the resistance to light the lamp. If you were able to vary the resistance evenly and to measure the current passing through as you got the joint tighter, you would find that the current varied evenly with the resistance. The more delicately you could vary the resistance, the more gradual would the changes of current registered be.

Now suppose you join a steel needle to one end of an electric circuit and a piece of coke to the other and arrange them so that the needle is lying loosely against the coke. Next you pass a current through the circuit. At the point where the needle and the coke touch there is a good deal of

resistance ; because they touch quite loosely there is not much of a path for the electrons to pass through.

Next you have some way of altering the closeness of the needle and the coke ; the closer they touch, the more current they allow to pass, and the looser they touch, the more current they prevent from passing. You have a loose joint in

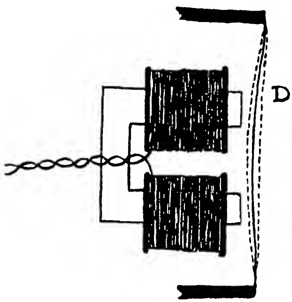


FIG. 53.—How a telephone turns electric currents into sound waves

your circuit capable of varying the resistance and you can of course measure this variation by putting into the circuit some kind of measuring instrument.

Suppose you put into the circuit something like Fig. 53. Here we have an old friend in a new disguise ; you will recognize the electromagnet which we first met in the bell circuit. There is however one difference of great importance ; the iron inside the bobbins is a permanent magnet.

That is to say, that whatever the current may be doing in the windings round the bobbins the iron is already magnetic independently, and the electromagnetism from the current either increases or decreases the total amount of magnetism. If a direct current is moving in the circuit at greater or less strength from moment to moment, every time its strength changes the magnetism changes. Sometimes the electromagnetism helps the natural magnetism of the iron bar and sometimes it cancels it out.

In Fig. 53 you see a piece of iron marked D a short distance from the end of the magnet. When there is no current passing through the circuit, D is attracted towards the magnet ; when the current increases the magnetism, it is attracted still nearer ; and when the current cancels out the magnetism, it is allowed to fall back a little distance farther. You will see the three positions sketched in the drawing.

Consider the way in which the circuit will work. It consists of the loose joint made by the needle and the piece of coke, a battery to produce a current and the electromagnet with the piece of iron in front of it.

We can vary the resistance of the loose joint and every time we do so the amount of magnetism will vary at the other end of the circuit and the piece of iron will be pulled back and forth accord-

ingly. The piece of iron will move exactly as often as we vary the resistance at the loose joint. How shall we vary it, and how often shall we vary it?

Let us vary the resistance at the loose joint 264 times in one second. How shall we do this? It sounds rather difficult, doesn't it? It is hardly possible to tap the needle in any way as often as that. This is how we shall do it: we will sing the note Middle C. Ah-h-h-h-h. What have we done now? We have set the air trembling 264 times a second; and the trembling air makes the delicately suspended needle tremble against the piece of coke 264 times a second also. And every time the needle trembles the resistance between it and the coke is altered, since the joint tightens up and loosens each time. And so a different amount of current goes round the circuit, changing 264 times a second and changing the amount of magnetism in the magnet 264 times a second. This makes the piece of iron opposite the magnet tremble 264 times a second and so the air in front of the iron also trembles 264 times a second—with what result? Why, that anyone who puts the iron *diaphragm* near his ear hears the note Middle C. In short, here you have in the needle and coke your *microphone* and in your magnet and iron diaphragm your *telephone*.

The difference between a spark transmitter and

receiver and modern wireless is that nowadays we pass all our signals at one end through a microphone and at the other through some sort of telephone. We arrange the transmitting circuit in such a way that the oscillations it sends out have printed on to them, as it were, the variations set up through a microphone. Then we arrange our receiving circuits so that these variations are detected unchanged by a telephone.

I wonder if you have seen a very big difficulty that ought to be puzzling you. How frequent are the oscillations sent out by a wireless transmitter? Millions a second, aren't they? Well, since the human ear can only hear oscillations of between, shall we say, sixteen and a few thousand per second, how can we hear the wireless oscillations? Is it really possible to make the telephone diaphragm tremble at such a pace? Of course not, and if it were possible it would be useless since no ear could hear them. The solution of this difficulty will occupy our attention in the next section.

IV. HOW WE ARRANGE FOR A WINGED HORSE TO CARRY THE SOUNDS FROM THE TRANSMITTER TO THE RECEIVER, FROM THE MICROPHONE TO THE TELEPHONE

Hertz's oscillator sent out its ether waves by discharging across a spark gap, and the shape of

these oscillations was like the wavy line which you saw in Fig. 25, G. Turn back and have a look at this. You will notice that a very important point about it is that each oscillation is smaller than the last, just as in the case of the water trying to find its proper level in the bent glass. Very soon the oscillations die down completely and have to be started up again. Such oscillations are called damped oscillations. They are no good for the purposes of modern wireless telephony. For this we require undamped oscillations, which go on without getting smaller each time. Fig. 54, *a*, shows you how they look compared with Fig. 25, G.

The modern wireless transmitting station sends out a continuous train of oscillations like these. We call it the Carrier Wave. The oscillations of a station sending out a three-hundred-metre wave have a frequency of one million. That is to say, that such a station begins its labours by creating undamped oscillations changing their course in the circuit a million times a second. If there were one million ups and downs in Fig. 54, *a*, then the picture would represent the carrier wave of this station.

Now this carrier wave will set up the same sort of oscillation in every receiving aerial it meets, and if the aerial circuit is properly tuned that oscillation will pass on to the detector circuit. But in

itself it will never be detected. No ear can hear an air wave of a frequency so high, even if we

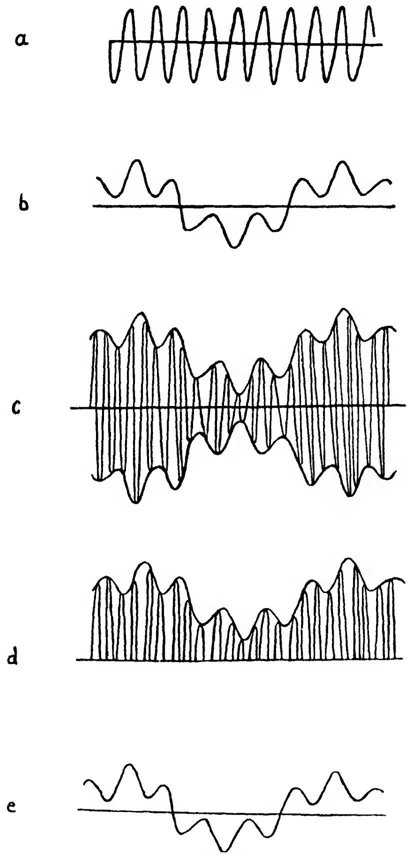


FIG. 54.—The carrier wave and the audio-frequency wave.

could invent a telephone so delicate that it could change the oscillations into air waves. How then

do we detect wireless programmes? Here are the necessary steps:

1. *At the transmitting station:*

An oscillation at *radio-frequency* is kept continuously going.

2. *Also at the transmitting station.*

A circuit containing a microphone is joined to the circuit producing the carrier wave. You know how the microphone works and so you can see how variations of current at *audio-frequency* can be set up in the microphone circuit. These variations are passed on to the circuit making the carrier wave and joined to it. When this happens the carrier wave is no longer steady as in Fig. 54, *a*, it varies according to the audio-frequency oscillations. If the audio-frequency oscillations produced through the microphone are like Fig. 54, *b*, then the carrier wave altered by them will look like Fig. 54, *c*.

3. *Through the ether.*

These altered oscillations set the ether in motion and the ether waves will be of exactly the same altered nature as was suggested by Fig. 54, *c*.

4. *In the receiving set: (a) aerial circuit.*

The aerial circuit is set oscillating, if it is properly tuned with exactly the same oscillation as left the transmitting set; that is an oscillation consisting of a carrier wave at radio-frequency

altered by the microphone's contribution at audio-frequency. This is passed on by inductive coupling or in some other way to the detector circuit.

5. *In the receiving set : (b) detector circuit.* The job of the detector circuit is to sort out the audio-frequency part of the oscillations and make them audible, and to get rid of the unwanted radio-frequency part.

I think that a very clear way to sum up the task of wireless is to compare it with what has to be done to make ordinary telephoning possible. Think what happens when I telephone to you. I change air waves set up by my larynx into audio-frequency changes in an electric current, and to do this I use a microphone. At your end the telephone turns back the audio-frequency changes of electric current into air waves, thanks to its changing magnetic strength acting on a diaphragm and so on the air around.

Both these processes happen in wireless, but between them something else must be done : the audio-frequency changes in current must be given a winged horse to carry them over space without wires, and then we must make them dismount at the end of their journey. The winged horse is the carrier wave set up by radio-frequency oscillations. Its only use is, as its name suggests, to

carry what we want to the place at which we want it.

How do we get rid of the carrying oscillations at the end of their journey?

V. HOW A PIECE OF CRYSTAL SORTS OUT THE USEFUL FREQUENCIES AND PREPARES THEM FOR THE TELEPHONE TO TURN INTO SOUND

In Fig. 55 we have a new kind of circuit. Several things about it need no explanation at this stage. On the left you will see a coil with variable coupling, and you know that through this coil is introduced by inductance the oscillations set up

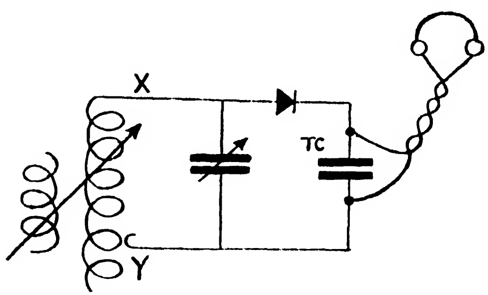


FIG. 55.—Diagram of a crystal detecting circuit.

in an aerial circuit. You note too that this coil can not only be varied in its coupling with the coil in the aerial circuit, but that it is also a variable inductance itself. With the help of the variable condenser to the right of it, it can be used to tune the circuit. For this detector circuit

must of course be tuned to have the same LC value as the aerial circuit and the circuits in the transmission stations.

Also it is worth while noticing that this coil has a good many more twists in it than the primary coil to which it is coupled. Evidently the designer of the circuit wants to *step up* the electric pressure as it enters the detector circuit.

On the right-hand side of the figure you will see what you can easily guess represents a pair of telephones, and you see that the wires leading to them are joined to the circuit on either side of another condenser, this time a fixed one. All this your reading has made you understand at once ; but there is one more item that is a complete mystery for the moment. The black triangle at the top is the sign for a *crystal detector*.

In 1874 a German, named Ferdinand Braun, discovered that crystals had a very special and peculiar way of treating currents passing through them. Whereas a piece of copper wire, let us say, allows a current to pass through it either way, a crystal lets a current through one way but offers a very high resistance to it the other way.

The dark triangle in our circuit diagram represents some kind of crystal against which there is stuck a sharp end of wire often called a " cat whisker " arranged in such a way that it can be moved about until the right spot on the crystal

has been found. Then the current set up in the detector circuit by inductance from the aerial circuit moves round until it reaches the crystal. During the first millionth of a second or so it will reach the crystal along the top line of the diagram and then it will change its direction and approach the crystal along the bottom line. This will go on in time with the oscillations received by the aerial, a current of electrons trying to pass through the crystal in opposite directions alternately.

Now let us follow the electrons trying to get through the crystal along X and let us suppose that this is the direction from which the crystal willingly permits electrons to pass. The electrons continue their journey until they reach the top plate of the telephone condenser, marked TC. Thus during this fraction of a second the top plate of TC becomes rich in electrons.

During the next fraction of a second the electrons move in the opposite direction and ordinarily the extra electrons on the top plate of TC would rush back; but they cannot, because the crystal does not allow electrons to move back in that direction. So the electrons are trapped; they cannot pass out of the electron trap which we have put into the circuit. Is there a back door through which they might escape? Yes, you have only to look at the diagram to see that electrons trapped by the crystal on the top of the

telephone condenser will try to get out through the wiring of the telephone.

During the minute fractions of time that the electrons are rushing up from the earth and making the lower plate of the telephone condenser rich, the upper plate will try to become positively charged by getting rid of its electrons towards the earth through this back door. But think of the way in which the back door is made: first, it is made of a very long piece of very thin wire, and you know that both *long* and *thin* mean high resistance; second, all this thin highly resistant wire is wound round the magnet in many close twists, and that means a great deal of inductance. What with the resistance and the inductance, the electrons, try as they may, cannot open the back door any more than the front.

So we reach this state of affairs: suppose a current oscillating a million times a second—that is, going through all its phases every millionth of a second; for the first two-millionth of a second the top plate of the telephone condenser fills up with a certain number of electrons; for the second two-millionth these electrons stay trapped; for the third two-millionth a new supply enters the trap; for the fourth two-millionth these electrons stay trapped; for the fifth two-millionth they are joined by another set of prisoners—and so on, until there are so many electrons in the

trap that pushing together they are able to break through the back door, altering the magnetism in the phones on the way and so making the diaphragm tremble.

You will see what the importance of this is: the electrons enter the trap through the crystal at *radio-frequency*, but they leave it through the back-door telephone at *audio-frequency*.

In this way the oscillations coming from the transmitter are sorted out, or, if you like, the audio-frequency is helped to dismount from the winged steed that carried it through the ether.

Turn back to Fig. 54; at *a* we saw the undamped oscillations created in the transmitting station to act as a carrier and bring the audio-frequencies over the ether. At *b* we saw the audio-frequencies impressed on to the carrier wave by electric impulses coming through the microphone circuit. At *c* we see the carrier wave, *a*, *modulated*, as it is called, by the microphone's contribution, *b*. This is the "shape" in which the waves leave the transmitting station and reach the aerial of your receiver. At *d* we see what the crystal does by cutting off half of each oscillation because it only allows electrons to move through it one way. Finally, at *e* we see the oscillations at audio-frequency, which are all that get through to the telephone magnet, so as to produce sound waves for us to hear.

Of course, all sorts of accidents may happen on the way. In the transmitting circuits there may be interference by way of stray currents creeping in from any point near by. Try to imagine what might happen if there was a conductor, an electric light wire for example, running parallel to some part of the microphone circuit. Every time the light was turned off or on, the electromagnetic field round the wire would form and collapse and lines of force cut across the near-by microphone circuit; and this might distort the shape of the audio-frequencies that ride the carrier wave. Or again on the journey through the ether every discharge of electricity in the atmosphere from thunder-cloud or other disturbance would print itself on to the wave—climb up on to the winged ether steed—and get carried to your receiving set. That is what we call static. Or if any circuit at either end was incorrectly tuned, or if the crystal trap had a leak, or if one circuit interfered with another circuit, producing unwanted induction effects—any of these and many other complications might bring it about that the shape of Fig. 54, *b*, and of Fig. 54, *e*, would be different, and those differences would mean that you would not hear correctly what the man at the microphone sang. Most of the complications that a wireless engineer has to worry about have to do with preventing all these accidents from having fatal results.

We have gone a long way from the worm's eye stage of the artificial electric eye. We can tune in and tune out ; we can hear sounds accurately ; but we cannot as yet *amplify* the signals that we get. This brings us to the last stage of our story. We must now be introduced to that part of a wireless set that seems to most people the really important part. We must examine the wireless valve.

CHAPTER IX

THERMIONIC VALVES

I. HOW EDISON NOTICED THAT BITS OF CARBON WERE FLUNG OFF THE FILAMENT IN AN ELECTRIC LIGHT BULB, AND HOW FLEMING LEARNED HOW TO USE THIS FACT FOR PRACTICAL PURPOSES

We come now to the fourth great name in the history of wireless, J. Ambrose Fleming, the inventor of that wonderful thing, the wireless thermionic valve.

Everybody knows something about valves, if it is only that they warm up, glow like a very poor electric light, and get out of order. The little books that tell us how to construct our own wireless sets are usually content to order us to fit in valve B.Q. 4 or X.Y. 3 in a certain position and we are happy to obey. If the noises come when we expect them from the finished set we are satisfied, and if they do not we send for a man from the wireless shop. And yet really to understand a thermionic valve is both fascinating and simple.

The story begins—so far as any scientific story

has a beginning—with that great American inventor, Thomas Alva Edison. Edison more than any other one man gave us electric light. He did this by putting a thin piece of wire or other substance inside a glass container from which the air had been pumped. Of course you know what he was doing in terms of molecules and electrons: he was setting up a high resistance to an electron movement. When the ends of the *filament* in the glass container were joined to a circuit and electrons were made to move in the circuit they crowded into the filament and banged the molecules about as we saw them do in Fig. 14. This set the electrons jumping and there was light.

Sometimes Edison used a filament made of carbon, which glowed without melting under the fierce bombardment of the electrons. He noticed that after a time the glass of the lamp began to look smoky, and it seemed that little bits of carbon must be torn away from the filament when it burned and be hurled against the glass. Remember that at this time neither Edison nor anyone else knew about electrons. So many things that seem simple to you who understand the atom and the electron were therefore very difficult for him to explain. So this matter of the carbon film on the glass of an electric lamp was just given the name of the "Edison Effect" and people wondered why, and left it at that.

Then came Sir J. J. Thomson's discovery of the electron and his proof that the strange glows and light discharges seen in vacuum glass tubes were caused by flights of electrons through the tube.[1] At once the Edison Effect was explained: the electrons torn from the filament and hurtling outwards into space carried with them whole atoms of carbon and deposited them on the boundaries of their glass prison.

Get hold of an old electric light bulb and break it very carefully, removing all the glass without destroying the filament inside. You will find that the filament consists of a very thin wire wound in a sort of net pattern on a glass support, and you will be able to see how the ends of this thin wire are joined to wires passing out of the glass at the bottom and made to join up to the terminals of the circuit inside the bulb socket. Fig. 56, A, shows a very early type of electric light bulb.

Now when the lamp is lit this filament wire gets very hot owing to its high resistance and then it does something not unlike what happens to a kettle of water on the fire. The molecules of water in the kettle get so banged about by one another that some get thrown off from the surface into the air. The steam engine is a device for using these water molecules that are banged

[1] You can read all about Sir J. J. Thomson's discoveries in my book *Inside the Atom.*

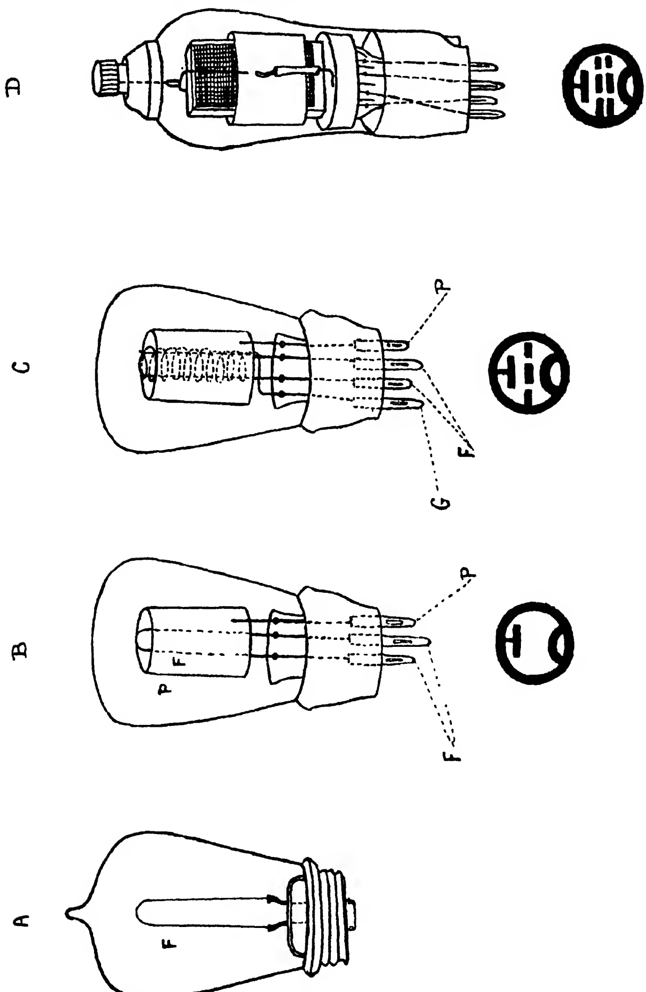


FIG. 56.—Stages in the development of valves. A, An early electric light bulb. B, A Fleming diode. C, A triode. D, A tetrode or screened grid.

away from their companions in this way, and the valve is a device for using electrons boiled off a filament.

For when the filament " boils " it throws off, not molecules, but electrons, which hang in a cloud round about and fall back on to the filament once more in course of time. They cannot get away because the glass stops them, and as the filament becomes positively charged with hungry protons by the loss of these electrons, they get attracted back again whence they came.

At this point Fleming comes in. He did for the electron boiler exactly what James Watt did for the steam boiler. Just as Watt said, " Let us use these molecules that are banged off from the surface of boiling water to do work for us," so Fleming said, " Let us use the electrons banged off from the electric light filament to do work for us." And so the idea of the thermionic valve was born. Let us see how Fleming harnessed the electrons from a filament on the boil.

II. HOW THE FLEMING VALVE IS THE SAME SORT OF ELECTRON TRAP AS A CRYSTAL, SO THAT IT TURNS AN OSCILLATING CURRENT INTO A ONE-WAY CURRENT

Suppose we provide the electrons shot off from the filament with an attractive landing stage. We will build a platform of thoroughly inviting un-

balanced protons inside the glass bulb near the filament; and we will arrange things so that however many electrons leap to satisfy these protons, the poor protons will be made immediately dissatisfied once more. How do we set about doing this?

We put a plate of nickel or some other metal inside the glass, but not touching the filament, and from this plate or *anode* we pass a wire through the glass and join it up to a battery which will keep the protons continually short of electrons. Next we connect up the other terminal of the battery to one of the filaments so that we feed back the electrons shot out by the filament into the filament again. We have now got a valve like Fig. 56, B. P is the plate, and F is the filament.

You can easily see what happens when the filament gets hot. Instead of just falling back on to the protons in the filament, the electrons rush to the protons in the plate or anode, and in this way a current is started round the circuit. This is called the anode current of the valve.

Now why are these glorified light bulbs called valves? As a matter of fact, in America they are not. They are called tubes; but valves is a very good name for them, as we are now to see.

A water valve is something which only lets water pass through it in one direction, and a thermionic valve only lets electrons through in

one direction. (It is called thermionic from the Greek word for heat, which we know best in thermometer, and the word ion with which we have already met at an earlier stage.)

The thermionic valve is exactly like a crystal in that it stops currents entirely one way and lets them through entirely the other. But it does not work on the same principle as a crystal, and though nobody exactly knows how a crystal does work, half a page will be enough to make the valve quite clear.

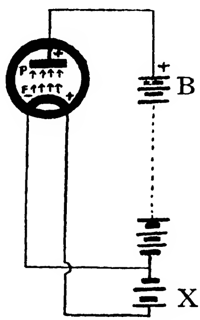


FIG. 57.—How the electrons are heated up and passed through the valve.

Fig. 57 shows in diagram form how the anode current goes: P is the plate kept positive by battery B, F the filament heated by battery X. The filament boils its electrons across to P and they are fed back to F again through the circuit. Suppose instead of the battery B, we have in our

anode or plate circuit some source of alternating current, then the alternator produces a current in the circuit, which makes P momentarily rich and then momentarily poor in electrons. When P is rich with electrons it will not attract any electrons from the hot filament ; they will just hang around in the bulb and at last drop back on to the filament again where their old protons are waiting for them. During this time, therefore, there will be no current running through the valve at all. There will only be a current during the times that the alternator is making the plate poor in electrons.

Now suppose that the alternator is the aerial circuit of the receiving set ; it is clear that we shall be able to use the valve in exactly the same way as we used a crystal. We pass the oscillations into the valve and out comes a one-directional current suitable for use in telephones.

This was Fleming's great discovery, valuable in itself but even more valuable because of the discoveries to which it led ; for all the modern wireless valves owe their existence to this first " Fleming Diode ". (What does *diode* mean ? It means having two electrodes, the filament or cathode and the plate or anode. There are also triodes, tetrodes and pentodes.)

III. HOW LEE DE FOREST ADDED A "GRID" TO FLEMING'S VALVE AND HOW THE GRID HELPED THE ELECTRONS ACROSS FROM THE FILAMENT TO THE PLATE

The hotter the filament in a Fleming Diode the more electrons are thrown off, and you might suppose that that would mean more and more electrons caught by the protons waiting in the plate or anode. But this is not so; experimenters found that the anode current did not get stronger and stronger, but that after a time the electrons from the filament got caught in a cloud in the space between the filament and the anode. They called this mass of electrons the "space charge", and as it was no use to anyone the problem was how to get rid of it.

The problem was solved by an American named Lee de Forest in a very ingenious way, which led to the remarkable discovery of how to *amplify* the signals sent out by wireless telephony.

Fig. 56, C, shows what de Forest did. Round the filament is a spiral fence, which does not touch either the filament or the plate. It leads down to a fourth leg, marked G, and it is called the grid. The sign for such a valve is drawn below, and the three lines between plate and filament are the grid.

Look carefully at the four legs of the triode: two come from the filament and join on to wires

leading to and from the heating battery. Another leads from the plate and joins on to the wire through which the anode current is made to pass, and the fourth leg joins the grid to a third circuit which we shall consider in a moment.

If you have ever seen a valve you will know that these legs are made to fit into sockets and that they are spaced unevenly so that you cannot possibly put a leg into a wrong socket. You will see now why this is important; it would be very bad to connect the plate to the warming battery, for example.

I think the reason why the valve is so confusing, when we just look at the set, is because it contains such different things in so little space. Even in the triode—and most valves are more complicated still nowadays—no less than three totally different circuits are allowed to come close together. If you remember that every circuit affects its neighbours in several different ways and that we have to protect every circuit from all undesirable interference, you will see how complicated the practical job of constructing valves and wireless circuits must be. It is important to remember this because all the precautions that have to be taken are very muddling indeed and we are apt to lose the main thread if we worry about them before thoroughly understanding the first principles explained in this book.

What is the use of the grid, seen as a spiral wire in Fig. 56, C, and as a broken line in the conventional drawing?

Suppose we connect up the grid by way of its leg to some battery or other source of electricity and make it negative, that is to say, fill it up with spare electrons. Then if the filament is heated, most of the electrons boiled off, it will be pushed back again on to it, by the repulsion of the electrons on the grid. A few only will get through the open spaces to the plate, and if we make the grid very rich in electrons none at all will get through because the lines of force from the grid-electrons will be close enough together to bar the way.

Suppose now we make the grid poor in electrons, that is, positively charged with many unbalanced protons, then it will help electrons across from the filament to the plate. Instead of their forming a hovering cloud they will rush through the gaps in far larger quantities. Thus the grid is rather like a traffic light controlling the traffic along the road between plate and filament. When the light is red, that is, when the grid is negatively charged, the traffic is stopped; when the light is green, that is, when the grid is positively charged, the traffic rushes forward far quicker than it would if there were no lights at all, although the lights take up a bit of space in the road. If there were

no traffic lights (no grid), the road would be a little clearer, but there would be traffic blocks (a space charge).

Thus the grid makes it possible to control the amount of the anode current from which we are going to get our signals; and it can be used in several different ways. First of all, as with the Fleming Diode the Triode with its grid can be used as a detector. You will remember that a detector has to do two things; first, it has to change the oscillating current into a series of one-way jerks of electron movement, by cutting out half of every complete change of the oscillation; and second, it has to deliver these jerks to the telephone at audio- instead of at radio-frequency. We saw how this was done by the crystal. Nowadays it is always done by using a valve, and there are two or three different ways of doing it. We saw that the anode current is a one-way current because it only passes when the anode or plate is positive; so we can have "anode rectification" with either a Diode or a Triode. There is also "grid rectification", and this is the best way in the opinion of most people. I do not think it is necessary to go into the kind of circuit that is required or into the rather complicated explanation of how grid rectification works; especially as we have learned to understand the main ideas of rectification and detection from the crystal circuit.

What we must spend time over is the way in which the grid can be used for another most important thing, and that is amplification.

IV. HOW THE GRID MAKES IT POSSIBLE TO AMPLIFY THE SIGNALS CAUGHT FOR US BY THE AERIAL CIRCUIT

Whenever the grid is given a negative charge, that is to say, given a surplus of electrons, it stops the traffic between filament and plate ; and whenever it is made poor in electrons, it speeds up the traffic. Now when it is a question of road traffic and lights, it does not need a very bright light to stop a great many cars, and a very weak light to stop only a few. Provided the light is strong enough to be seen at all, it will stop exactly the same number whatever its strength ; the number depends on the number of cars in the street.

In exactly the same way with the grid of a thermionic valve ; it may be quite feebly negative or positive, but the amount of traffic stopped or let through will depend on the number of electrons boiled off the filament ; and that depends chiefly on the heat of the filament.

So if we heat the filament very hot indeed, even a feeble change in the number of electrons on the grid will have a very great effect on the size of the anode current. In other words, the changes

in the number of electrons on the grid will produce amplified changes in the number of electrons passing through the anode circuit.

Very well then, join up the grid to the aerial circuit in a suitable way so that you get the oscillations caused by the ether waves making the grid now positive and now negative ; and join up your filament and plate to a telephone in a suitable way and what comes into the set via the grid will be amplified in passing through the valve and come out stronger at the telephone.

The number of electrons that are made to oscillate in the aerial circuit by waves sent out from a transmission circuit are far too few to record by themselves, so we boil up electrons in a filament, using for this purpose a battery ; and then we set the original oscillations to work a traffic light system to control their movements. And we are able to do this in such a way that their movements imitate all the changes that we want to detect in the original oscillations.

I do not pretend that there are no difficulties in carrying this into practice, but if you clearly understand what it is that your valves are doing, whether it is detecting or amplifying, you will have a clue which will carry you through later complications.

There are of course very many different ways of constructing the valve circuits in a powerful modern set. For example, there is *high-*

frequency amplifying and *low-frequency amplifying*. Suppose there are three valves in your set; it is probable that the first is amplifying the high or radio-frequency, the second cutting out the radio-frequency and leaving only the low or audio-frequency, and the third amplifying the audio-frequency.

Do you understand that sentence? Let us suppose that you have a three-valve set and that each valve is a Triode, that is, a valve with plate or anode, filament, and between them a grid; so that it has four legs to stand on. The grid of the first will be joined up to the secondary coil of a couple through which the oscillations caught by the aerial circuit are brought into the amplifying and detecting circuits. This grid will oscillate between too few and too many electrons exactly as the aerial circuit is doing, and these changes from positive to negative will set up far bigger changes in the current passing through the valve. The amplified high-frequency current is now passed on to the second valve, which is arranged to "rectify" it, that is, to turn it into a low-frequency current, and then this is passed on to the third valve and amplified once more.

You don't quite understand? Very well, let us take a careful tour from one end to the other of a three-valve wireless set. You will be surprised when you look at Fig. 58 to find that there is

scarcely anything in it that you do not understand completely.

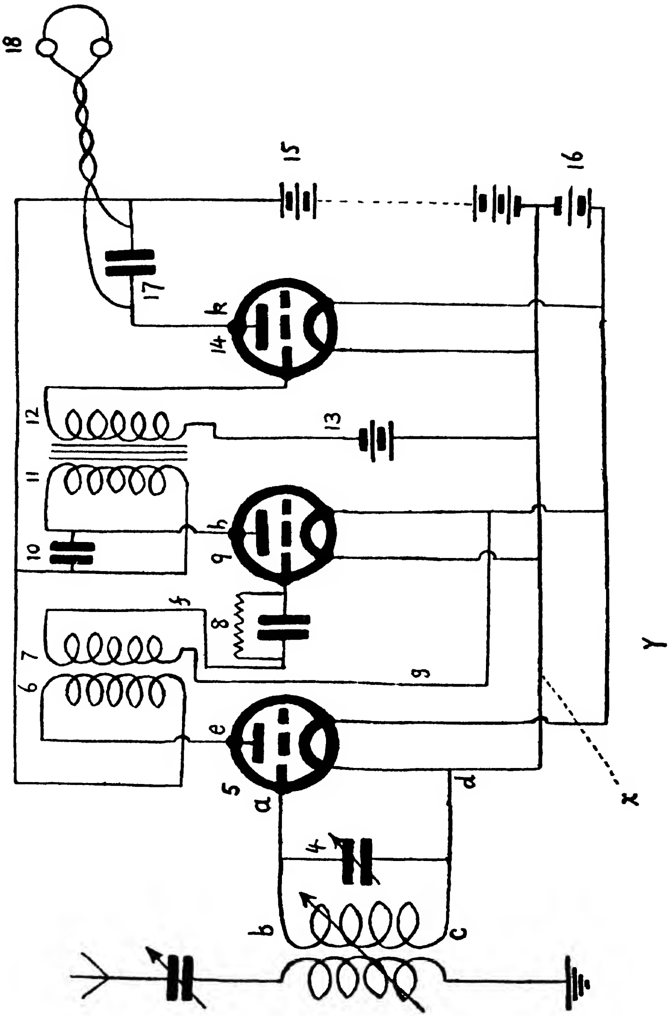
V. THE BEGINNING OF A TOUR ROUND A THREE-VALVE SET. THE AERIAL CIRCUIT AND THE THREE FILAMENT HEATING CIRCUITS

Fig. 58 is a complete diagram of a three-valve set and I do not think you are going to have any difficulty in understanding thoroughly everything that happens from the moment that oscillations are set up between the aerial and the earth to the moment when a sound comes out of the earphones at the other end.

First of all remind yourself of what is being done at the distant transmitting station. A high-frequency carrier wave is being oscillated and a low-frequency component is being pressed on to it through a circuit with a microphone in it.

As I look at that sentence that I have just written I wonder if you are going to remember all that it means; and I am going to make quite certain that you do by giving you the reference back to the page upon which each point was originally explained. Be sure to turn back whenever things are not perfectly clear.

High frequency,—page 234.
Carrier wave,—page 234.
Low frequency,—page 236.
Microphone,—page 228.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X
4
b
c

This modulated (p. 236) carrier wave is really a series of electromagnetic fields forming and collapsing perhaps a million times a second (p. 98) and cutting across (p. 168) any conductor they happen to meet, whether just a wire clothes line or your aerial.

When this wave reaches your aerial circuit, it sets up oscillations of exactly the same sort as were originally sent out by the transmitter. To get these oscillations at full strength your aerial circuit has to be tuned (p. 156). To do this we include in the aerial circuit 2 and 3, a variable capacity and a variable inductance (p. 195).

We have spent so much time over the working of an aerial circuit represented by numbers one to four in our drawing that there is no need to say more. We know that, thanks to our tuning, oscillations made up of a high-frequency carrier wave modulated by a low-frequency component from the microphone circuit is agitating the electrons in our aerial circuit, completely unknown to us, and that our job is to detect it. In order to detect it we have to get rid of the high frequency altogether and turn the low frequency back into sound waves. To do this we pass on the oscillations through an inductance coupling (p. 172) into a different circuit.

So far so good. Now before we examine the rest of the set in detail take a look at the diagram.

Remember that the shape of the drawing has nothing to do with the shape of the set. It is a purely conventional drawing arranged to look neat on paper, and if you were to make the set you would have to arrange the parts to fit a suitable box, and you can do this in any convenient way provided you do not change the order of the parts in the circuit.

Next remember the very important little detail that wherever two wires are drawn with a little loop at their point of crossing it means that the wires do not really join up at that point. For instance, at the bottom of the drawing there are three such loops, and this is simply a conventional way of showing that the three wires drawn vertically do not have anything to do with the horizontal wire across which they are looped. This little point makes the drawing much easier to understand.

Let us take those two lower lines that I have marked *x* and *y* and consider the circuits of which they are part. In the corner is no. 16, a small battery. The wire *x* leads from one leg of each filament to the negative side of battery no. 16 and the line *y* leads back again from the other leg of each filament to the positive side.

We already understand all about the lowest part of the diagram, there are three circuits there and their use is to boil up electrons in the three

valves 5, 9, and 14. It may be a useful thing for you to draw the diagram carefully for yourself and to take a red pencil and go over each part as you understand its use. You can now red pencil the aerial circuit and the three circuits between 16 and the three filaments of the valves including the wires *x* and *y* and the three vertical wires looped over *x*. You see how the filaments are warmed and so we now have the electrons nicely cooking in each valve and waiting to be used by the oscillations that we are introducing from the aerial circuit.

VI. WHAT HAPPENS TO THE SIGNALS AS THEY ARE PASSED THROUGH THE FIRST VALVE. ONE STAGE OF HIGH-FREQUENCY AMPLIFICATION

Our next job is to introduce the oscillations caught in our aerial circuit to the detector and amplifying circuits. This is done through the variable inductance couple no. 3 (p. 172). With the help of the variable condenser no. 4 this circuit, *a*, *b*, *c*, *d*, is in resonance (p. 156) with the aerial circuit. One end of the circuit is joined at *a* to the grid of our first valve and the other through *d* to one leg of the filament. In *a*, *b*, *c*, *d*, exactly the same oscillations are going on as were originally sent out by the transmitter ; at one moment the grid at *a* is made rich in electrons and at the next it is made poor ; or in other words, the grid

of valve 5 is alternately and very rapidly holding up and hurrying on the electrons boiled off from the filament and anxious to get to the plate.

The effect of this is that instead of having to rely on the tiny original oscillations we simply use them to impress the electron streams (I almost said "steam") boiled off the filament, with their original form or shape.

The signals that began their career in our aerial circuit and are finally going to reach our ears at no. 18, the telephones, have now reached the point *e*, at the top of valve 5. Get well into your head what has happened to them at this point. First they have been through a valve, and therefore they are no longer an alternating current. They have got into the one-way circuit which passes from filament to plate, and in this circuit they can only go *from* filament *to* plate, and not from plate to filament.

Second, nothing has been done to them to change them from radio-frequency to audio-frequency (p. 237). It is true that they are no longer oscillations, but one-way gushes, but these gushes are following one another at rates of the nature of millions to the second, so that they are of no possible use to us as far as hearing is concerned.

Third, thanks to the amplifying abilities of the grid of a Triode (p. 257), the one-way current that is passing through the point *e*, although it bears

with it exactly the same variations as the original current, has those variations strengthened. In short, we have put our original signals through *one stage of high-frequency amplification.*

There is a little point that I might mention again here. I think it is because of the word "current" and the ideas we get from flowing water, but many people cannot get it out of their head that the *same* electrons go through all these adventures all the way from the aerial to the telephone. Of course this is absurd. What happens is that one set of electrons is used to influence another and no one electron ever gets very far around the circuits.

Before we follow up our signals in their new form after they pass through the point *e*, let us remind ourselves of an important point about the plates of our three valves. They must all be kept starved of electrons, so that they may be hungry for the electrons anxious to pass to them from the three filaments, and so if you look at the diagram you will see that each of the plates is connected in some way with the battery no. 15. You can trace with your red pencil the connection between plates and this battery and you will know that these wires have as one of their jobs to keep the plates hungry.

We must now follow our signals from *e* to the object marked 6. The circuit loops across a wire

and into what is clearly a coil. The shape of this part of the circuit and the way the wire is looped is only to make the drawing neat and compact.

Where does the current carrying our signals go now? Through the coil and on, do you think? Where does this lead? Only to battery no. 15, and that will do us no good. No, we must follow our signals now into yet another circuit which they are able to enter thanks to the couple marked 6 and 7.

VII. THE SIGNALS PASS TO THE SECOND VALVE AND ARE RECTIFIED AND THEN THEY CONTINUE TO THE THIRD AND LAST VALVE TO RECEIVE ONE STAGE OF LOW-FREQUENCY AMPLIFICATION

We have followed our signals round through the point *e*, until they reach no. 6. You will of course know what 6 is at once (p. 172). It is the primary and the right-hand coil 7 the secondary of a couple. Through the primary coil, 6, go the signals and by induction they transfer themselves to a new circuit through the secondary coil, 7.

Remind yourself of how the change over works. First of all it is the cutting across of magnetic lines of force that sets the electrons moving in the secondary coil (p. 166), and you know that this only happens when the number of lines of force

cutting the coil at any moment is increasing or decreasing. We have already seen the signals, transferred from one circuit to another by inductance through the coil 3. There it was an oscillating current so that the secondary coil was all the time being cut by a varying number of lines of magnetic force. But at no. 6, there is a slight difference. The signals have not come from the direction of *e* in oscillations, but as a one-way current. But this current is not a steady current or else there could be no induction between the primary and secondary coils (p. 167). Although it is not an oscillating current it is a series of gushes, stopping and beginning again a million times a second, so that the number of lines of force cutting across the secondary coil varies from moment to moment. When they are growing they induce a current in one direction and when they are collapsing in the other, so that our signals when they enter a fresh circuit at no. 7 become once more an oscillating current. They are now oscillating in a circuit that contains the following things, the secondary coil no. 7, the point *f*, a mysterious object marked 8 leading to the grid of the second valve no. 9, the point *g* and one leg of the valve filament. What happens in this circuit? You will notice two differences in the circuit as compared with the circuit *a*, *b*, *c*, *d*, which we studied a little while back. Though

there is still a path ending in a grid at one point and in a filament leg at the other, there is a new object no. 8 and also it is the other filament leg that is involved.

Now I think it would be quite easy for you to understand the use of no. 8, the grid leak, as it is called, and also why the circuit is joined up to the other leg of the filament, but it would take a long time to explain and make the description of the set as a whole rather longer than is wise for the moment. We will discuss it therefore in very general terms. The signals are now carried along in a current oscillating between the grid and the filament of no. 9. This oscillating current contains two components, the high-frequency carrier wave and the audio-frequencies that we are really interested in. The arrangement of this circuit prepares the audio-frequency component so that it is in a suitable shape, when later the radio-frequency component is weeded out, to be passed on to the telephones.

It is as if this circuit shook the two sets of frequencies loose from one another and then handed them over to the anode current. When the signals pass out of the second valve at the point *h*, they are in the form of a one-way series of gushes with the two original components loose from one another, and in this condition they pass on to nos. 11–12, which, as you see, is once

more two coils coupled together. What is the meaning of the three lines drawn between the coils? They indicate that unlike the last couple nos. 6–7 which was wound on a bobbin of wood, this couple has an iron core. The effect of the iron core is to pass on low-frequency currents by induction, but to hold up the high frequencies; in other words, the secondary coil no. 12 accepts from the anode current circuit of the last valve only the audio-frequencies, and so the job of *detecting* has been done. From now on we have only got the low or audio-frequencies left and we can therefore hear the signals through a telephone, when we are ready.

When the current reaches 12 and 12 refuses the radio-frequencies, something has to be done with them; and so we insert a back door for them to go through and that explains the "by-pass condenser" no. 10.

We have now got our signals in the form of a low-frequency alternating current, for of course the induced current in the secondary coil no. 12 is once more an alternating current, for exactly the same reason as the gushes became an A.C. in the secondary no. 7.

The signals are by now very much stronger than they were and also rectified and ready to produce audible sound waves in a telephone; but even now we are not quite content. We

decide to amplify them still more, so that just as we had a stage of high-frequency amplification to begin with, we are now going to have a stage of low-frequency amplification. We therefore apply the current to the grid of our third valve.

Into this circuit we insert a small battery no. 13 because the signals are now so strong that the third valve must be a "power valve" which needs its grid helped by a battery. Otherwise nothing new happens here. The signals influence the charge on the grid, and the grid acts as a pair of traffic lights on the third anode current. Our signals leave the third valve at *k* pass to a telephone condenser no. 17 (p. 238), and then at last we hear the crooner who is standing out of gunshot at a microphone in the transmitting station. He had better do his best considering all the trouble that has been gone to for centuries to allow him to perform.

VIII. THE END OF THE BOOK

I hope that it will not disappoint you to hear that the three-valve set we have been studying would never be used in a practical receiver to-day. We chose it because it is simple and useful for explaining general principles, and if you thoroughly understand it, you will not have difficulty in following more useful circuits and arrangements.

There are two further important matters that we

must glance at before bringing our study to an end. First of all, we must say something about the complicated-looking valve shown in Fig. 56, D. It is a very common object in wireless sets and is called a screened grid valve. It is exactly like the triodes we used for our three-valve set, except that it has an extra grid, between the first grid and the plate. The use of this second grid is to smooth out the work of passing over the boiled-up electrons from the filament to the plate. In high-frequency amplification the three-electrode valve with only one grid produces jerks and unevennesses and very often starts to oscillate on its own. This distorts the signals and is of course a perfect nuisance to the neighbours, for the electromagnetic fields of an oscillating valve in a local receiving set go out in all directions, jump on to the carrier wave horse of any incoming honest wave and cause misery of all sorts.

In the same way as a more complicated valve is used for the stages of high-frequency amplification, so too a still more complicated valve, the pentode, is used for the low-frequency stages.

The other matter about which a word must be said is "heterodyning". Heterodyne and superheterodyne receiving sets have circuits in them which set up special private oscillations which can be added to the incoming wave in such a way as to improve the amplification and the selectivity.

But once we start considering all the possible modern circuits we shall need a thousand more pages. It is not the purpose of this book to give you a full knowledge of modern practical wireless but to try to make the first principles thoroughly clear. Once you are certain that you understand about inductance and capacity, resonance and rectification, aerial circuits and valve circuits, then all that you have to do is to fill in the details. You will certainly find your brown box far more interesting now that you understand what it is all about, than if it remained a mere bag of tricks.

In glancing through the history of how wireless came, you must have been struck by the way in which hard work and lucky accident in all parts of the world had to be joined together to produce the astonishing result. No one man invented radio, not even a score of men, it is the invention of civilized humanity working together and pooling knowledge. Every country contributed to the discovery and without the help of any one people science is always held back. It is for us to see to it that wireless is used to bring all nations together in closer unity so that science may advance even further.

There are many wonderful scientific discoveries still to be made and we can all help to bring them about in one of two ways. Either we can learn

to be scientists, that is to work hard and to learn to profit by lucky discoveries, or, if we are not ourselves fitted to be scientists, we can make the world a place in which knowledge can prosper. So much of scientific invention is found valuable for purposes of war and destruction that some people are stupid enough to think that war helps on scientific advance. It is true that aeroplanes would not be as wonderfully developed as they are to-day, but for the fact that we are all anxious to find out how best to bomb the other fellow; but in the end war destroys even while it builds.

Wireless ought to be a great help to peace. The ancient Greeks, who started the whole thing by rubbing amber against their sleeves and wondering about the mysterious stone from Magnesia, taught that no state could be successful unless all its citizens could gather within the sound of one voice; many of us feel that there will not be peace on earth until there is some sort of a world state. Wireless makes it possible for the citizens of even a world state to gather within the sound of one voice, to learn, to discuss, to understand, to enjoy the same things, to know all that is going on. If when we think of the wonderful genius of men like Clerk Maxwell, Hertz, Marconi, Edison, to mention four men of four different great nations, we feel like honouring them, how better could we do it than by using their great inventions

solely to bring peace and good-fellowship between the four nations to which they belonged and all the other nations, each of which contributed to the coming of wireless?

SOME BOOKS ON WIRELESS.

THE ADMIRALTY HANDBOOK OF WIRELESS TELEGRAPHY.

This is by far the best book on wireless, and any boy who has read *How Wireless Came* should have but little difficulty in finding his way about in it.

RADIO COMMUNICATION AND CATALOGUE OF WIRELESS TELEGRAPHY AND TELEPHONY.

With these two booklets in his hand a boy should go through all the collections at the Science Museum, South Kensington. He will see all sorts of historic apparatus from the days of Hughes, Hertz and Lodge.

SIGNALLING THROUGH SPACE WITHOUT WIRES.

By Sir OLIVER LODGE.

HISTORY OF RADIO TELEGRAPHY AND TELEPHONY.

By BLAKE. (*Radio Press*, 1926.)

Any of the books by Sir J. Ambrose Fleming will be found easy to understand and brilliantly written.